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THE RÔLE OF THE GLACIAL ANTICYCLONE IN THE AIR CIRCULATION OF THE GLOBE.

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The Fixed Anticyclones Above Existing Continental Glaciers.

The Anticyclones as Agents of Glacier Alimentation.—In two monographs published in 1910[1] and later in my "Characteristics of Existing Glaciers,"[2] a theory of fixed glacial anticyclones centered over the snow-ice masses of Greenland and Antarctica was put forward upon the basis of a comprehensive review of the results of polar exploration. This theory furnished an explanation for the nourishment of these inland-ice masses through adiabatic melting and vaporization of the ice particles of the cirri, as they are drawn down within the vortex of the anticyclone, and the precipitation of this moisture, generally as fine ice needles, when it comes into contact with the glacier surface and the cooled air layer immediately above it. The obvious application of this theory of alimentation to the even greater continental glaciers of the Pleistocene and earlier glacial cycles, was made in a separate contribution.[3] For these fixed anticyclones themselves, which are deserving of a special name, so much evidence has now accumulated that their existence can hardly be disputed, though differences of opinion will no doubt arise concerning their dominance over or dependence upon the usual migrating cyclonic and anticyclonic movements in the atmosphere.

The Northern and Southern Glacial Anticyclones Compared.—That a great fixed anticyclone exists within the south polar region

[1] "The Ice Masses on and About the Antarctic Continent," *Zeitsch. f. Gletscherk.*, Vol. 5, 1910, pp. 107–120; "Characteristics of the Inland-ice of the Arctic Regions," *Proc. Am. Philos. Soc.*, Vol. 49, 1910, pp. 96–109.

[2] Macmillan & Co., New York and London, 1911, Chaps. IX. and XVI. and afterword.

[3] W. H. Hobbs, "The Pleistocene Glaciation of North America Viewed in the Light of Our Knowledge of Existing Continental Glaciers," *Bull. Am. Geogr. Soc.*, Vol. 43, 1911, pp. 641–659. When this theory of alimentation was announced, I supposed it to be new to science. Professor Hans Crammer has since called my attention to a little-known paper by Fricker published as early as 1893, in which a similar idea was made as a suggestion and at a time when there was little known which could have been cited in its support. (Dr. Karl Fricker, "Die Entstehung und Verbreitung des antarktischen Treibeises," Ein Beitrag zur Geographie der Südpolargebiete. Leipzig, 1893, p. 96; also "Antarktis," Scholl und Grund, Berlin, 1898, pp. 187–188.)

seems to have been early recognized by a number of scientific men, due especially to the writings of the late Sir John Murray, Bernacchi and Buchan. By them it was, however, assumed that this condition was determined in some manner by the earth's southern geographic pole, and was not connected with the inland-ice. A like natural tendency to regard movements within the lower atmosphere as determined primarily by their positions relative to parallels of latitude, is more or less general. As an illustration, it is generally assumed upon the basis of few and scattered observations within all save the central European areas, that the ceiling of the troposphore in its descent from the equatorial regions reaches its minimum altitude above the geographic poles, though it is far more probable that in the northern hemisphere at least its minimum of altitude is to be found to the southward above the continental glacier of Greenland. In the southern hemisphere the Antarctic continental glacier is probably centered near the pole, and in consequence conclusions drawn from geographic positions are there relatively indecisive. During the winter season the great deserts of moderate latitudes become likewise the loci of anticyclones. Their influence upon the general circulation within the earth's atmosphere should be, however, relative to that of the inland-ice small by comparison. It is because the inland-ice masses have a domed surface that they permit the air which is cooled by contact to flow outward centrifugally and so develop at an ever accelerating rate a vortex of exceptional strength. As already pointed out in my earlier papers, this is one of the essential conditions for the formation of strong glacial anticyclones.

Their Strophic Action Believed to be Dependent upon an Automatically Recurring Disturbance of Balance Between Opposing Forces.

The Refrigerating Air Engine.—The strophic action of glacial anticyclones is one of their most marked characteristics, and would appear to be dependent upon the shield-like form of the glacier surface. Opposed to each other are here the abstraction of heat from the air above the glacier surface tending to make it slide off radially, and the increase of temperature due to resulting conden-

sation. Unlike the latter, which is determined by the measure of the vertical component of its fall, the contact cooling is in direct ratio to the time the layer of air rests upon the snow-ice surface. Conditions of calm therefore favor cooling and descent of air currents, as high wind velocity, does the warming and consequent retardation or even reversal of the descending current. It is not surprising, therefore, that the strophic glacial storms are initiated in calm conditions, "work themselves up" or become accelerated to accord with the acceleration of velocity of bodies sliding upon inclined surfaces (here further accelerated by increasing slope toward the margins), and bring about their own extinction when the air passes over the surface too rapidly for surface cooling to exceed or equal adiabatic warming. The sudden check in the outward flow of air, which is one of the most striking features of these strophic movements, in turn promotes new surface cooling and causes the precipitation of fresh snow within the zone of near contact to ice, thus often taking place with the sun but little obscured. In the automatic recurrence of similar movements the glacial anticyclone thus bears considerable resemblance to the hydraulic ram.

The Lines of Evidence for Fixed Glacial Anticyclones.

The Earlier Evidence.—The observational evidence which in earlier papers was adduced in support of the existence of the glacial anticyclone above continental glaciers, was drawn chiefly from the then available reports upon exploration of the inland-ice masses of Greenland, Antarctica, and Northeast Land (Spitzbergen). This evidence may be profitably summarized under the following heads:

1°. Centrifugal flow of surface air currents above inland-ice masses.

2°. Outward (centrifugal) sweeping of surface snow largely derived from the central areas, and its deposition and accumulation as a marginal fringe about the inland-ice.

3°. Snow in large part wind-driven above the sloping portions of the ice mass.

4°. Sudden warming of the air at the end of the blizzard—foehn effect in descending currents.

5°. Behavior of upper air currents and movements of the cirri.

6°. The evolution of the Antarctic blizzard and its termination.

7°. Areas of relative calm corresponding to the flat central bosses of the ice domes.

8°. Air highly charged with moisture within the flat central area of calms, and precipitation of snow or ice near the glacier surface.

Confirmation in Later Exploration.—In the three years which have elapsed since the appearance of my "Characteristics of Existing Glaciers," important new explorations have been carried out; the inland-ice of Antarctica has been twice penetrated to the southern geographic pole and new areas have been explored; several crossings of Greenland have been made along new routes; and full reports upon some earlier explorations have become available. It is proposed, therefore, to review the evidence and show how this has been enlarged by the recent observations; as well as to add evidence along hitherto undeveloped directions. Such a discussion of the evidence seems to be called for at the present time, since in a paper recently read before the Royal Meteorological Society, Brooks has presented this theory as his own, merely citing my book for references to glacial conditions.[4]

Evidence for More than One Anticyclonic Center Above Each of the Greater Areas of Inland-Ice.

Greenland.—The three transections of the Greenland continent which have now been made within the central and southern portions, have revealed the fact that there are at least two higher plains upon the snow-ice surface which are separated by a depression. This depression clearly lies to the northward of de Quervain's route, since his summit level is considerably lower than that of either Nansen or Koch and Wegener, though like Nansen's, his highest point is found near the east coast. The southern of the two nourishing centers of the Greenland ice-sheet is thus located toward the east coast and south of the Arctic circle, whereas the other center lies toward the west coast from the medial line of the continent,

[4] Charles B. Brooks, "The Meteorological Conditions of an Ice Sheet and their Bearing on the Desiccation of the Globe," *Quart. Jour. Roy. Meteorol. Soc.*, Vol. 40, 1914, pp. 53–70.

and in an as yet undetermined latitude, though certainly well to the northward of Disco Island (Fig. 1).

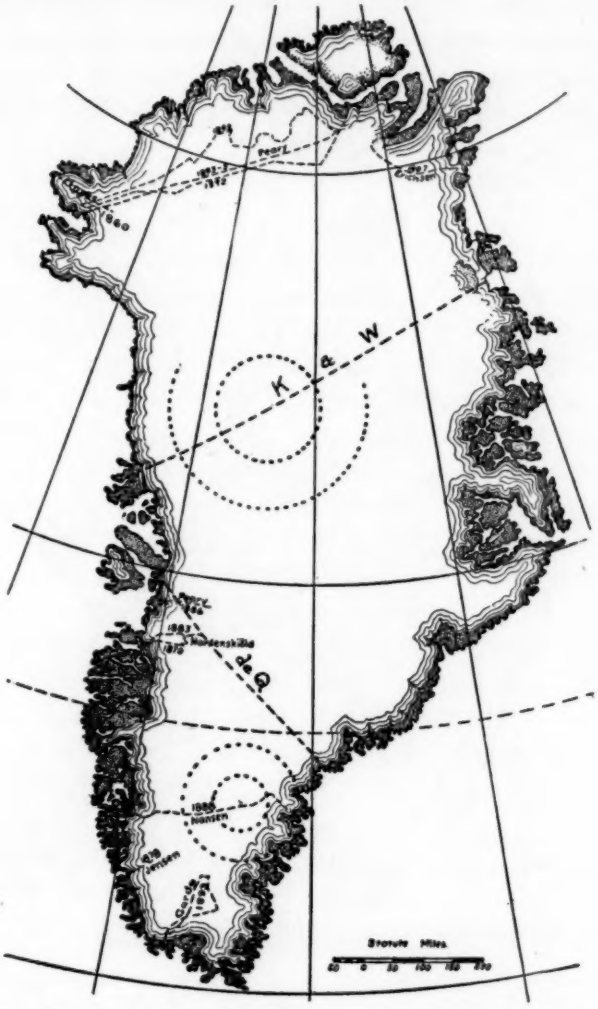


FIG. 1. Sketch map of Greenland to show roughly the position of the ice domes within the central and southern portions.

Antarctica.—This discovery that Greenland is provided with more than one nourishing center for its inland-ice, is wholly in accord with what has now been learned concerning the Pleistocene continental

glaciers of North America, which had the Keewatin, Labradorean and Patrician nourishing centers that repeatedly waxed and waned so as to reach their several maxima at different times (Fig. 2).

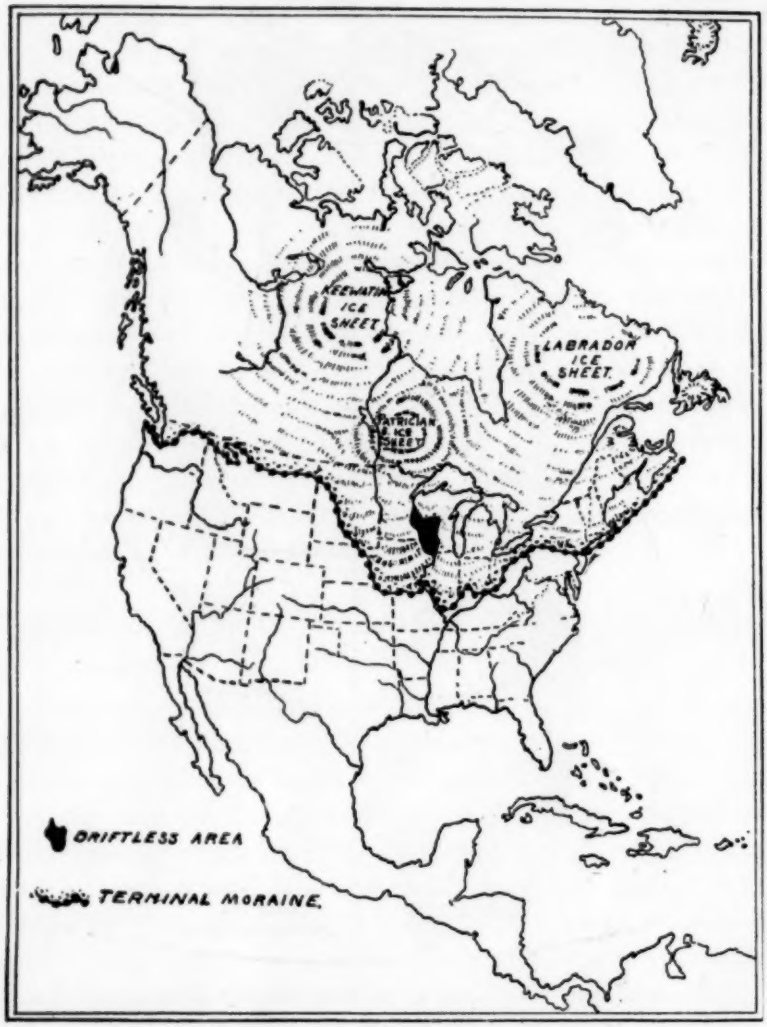


FIG. 2. Map showing the known anticyclonic centers of the Pleistocene continental glacier of North America.

From the Antarctic region the experiences of Mawson strongly indicate a near-by anticyclonic area probably located near the mag-

netic pole.[5] Within a vortex of this nature the wind velocity is determined by angular velocity multiplied into the radius, and hence one of relatively small dimensions should exceed in vigor one that is spread over a vast field and in which the steeper marginal area bears a smaller ratio to the whole. Mawson has expressed the belief that his base was near the center of a permanent anticyclone.[6]

The Centrifugal Flow of Surface Air Currents Above the Inland-Ice Masses.

Early Evidence from Greenland.—In 1911 when my work on glaciers was published, evidence was available upon this from both the eastern and western coasts of southern Greenland in latitude 64° (Nansen), from west Greenland in latitude 69° (Peary and later de Quervain and Stolberg[7]), from northwest Greenland in latitude 78–83° (Peary), and from northeast Greenland in latitude 77° to 82° (Trolle). With the exception of the first and last mentioned, these data applied exclusively to the western coast where the prevailing surface winds come from the easterly quadrants.

Later Confirmation.—The later evidence for the centrifugal flow of surface air is ample and throughout confirmatory. De Quervain, who crossed the inland-ice in 1912 between the latitudes of 66° and 68°, found head winds while ascending the west slope, but winds from behind during his descent to the east coast.[8] Referring to the low temperatures and the wide diurnal temperature range within the central area, de Quervain says:

> "It is the cold air of this middle part which even in summer streams like water from off the high surface toward all margins, deviated to the right in consequence of earth rotation" (p. 137).

Measurements of snow temperature made at different depths show

[5] Sir Douglas Mawson, "Australasian Antarctic Expedition 1911–1914," *Geogr. Jour.*, Vol. 44, 1914, pp. 257–286.

[6] L. c., p. 69.

[7] The first Swiss expedition, which penetrated some seventy miles from the coast (A. de Quervain und A. Stolberg, "Durch Grönlands Eiswüste," Strassburg, 1909).

[8] A. de Quervain, "Quer durchs Grönlandeis, Schweizerische Grönland-Expedition 1912–13." Reinhardt, München, 1914, 196 pp., 15 pls., 37 figs. and map. Also personal communications.

how exactly the air temperature follows that of the snow (p. 94). The diary of the journey (pp. 85–104) shows that for the first three weeks on the inland-ice the wind blew almost uninterruptedly down slope from in front, became more variable and shifting on the plain with slope a few seconds of arc, and reversed direction and blew from the northwest soon after passing the divide, where slopes became 8′ of arc to the eastward.

Koch and Wegener in their transection of the Greenland continent at its widest section (between latitudes 72° and 73°) encountered essentially the same conditions, the outward blowing currents constituting a veritable succession of storms whose vigor increased toward both margins of the section.[9]

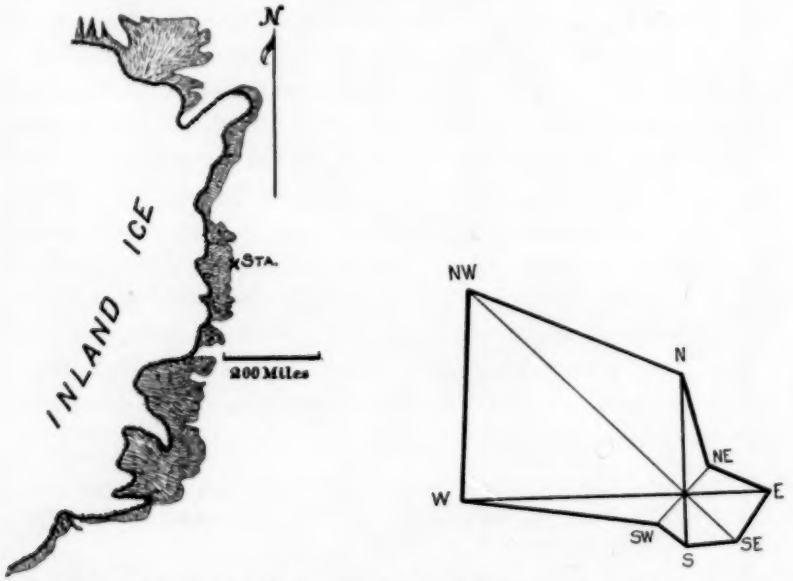


FIG. 3. Frequency wind-rose at Danmarks-Haven in northeast Greenland and (at the left) a sketch map showing location of the station with reference to inland-ice (after Wegener).

From northeast Greenland there was available at the time of my earlier discussions of the glacial anticyclones, only a preliminary

[9] J. P. Koch, "Unsere Durchquerung Grönlands 1912–1913," *Zeitsch. d. Gesellsch. f. Erdk. z. Berlin*, 1914; Alfred Wegener, "Vorläufiger Bericht über die wissenschaftlichen Ergebnisse der Expedition," ibid.

statement concerning the prevailing direction of surface winds at the Danish base near Cape Bismarck. More recently (1911) the full meteorological report by Wegener has been issued; and, confirming the earlier statement, shows that all strong winds come from the westerly (inland-ice) quadrants. The frequency wind-rose to cover the entire period of two years over which the observations extended, is reproduced in Fig. 3.[10] If the wind force had been taken account of, the easterly sections of the rose would have almost disappeared, since easterly winds are always light sea breezes, which at an elevation of only 1,000 meters have been completely overwhelmed by the northwest winds.[11] In this rose the dextro-rotatory deviation of the down-slope winds is apparent.

Early Evidence from Antarctica.—Over the Antarctic inland-ice the law of surface air circulation had been clearly indicated by the results of exploration at the time of my early discussion of the subject. The more important data had been derived from the sledge journeys of Captain Scott, Sir Ernest Shackleton, Professor David and Dr. von Drygalski. As early as 1902 Captain Scott had ascended the Ferrar glacier outlet to the inland-ice above the mountain rampart and pushed west southwestward over it for a distance of two hundred miles, ascending on ever decreasing grades to the farthest point attained, and encountering winds of nearly constant direction coming from the south-southwest. The prevalence of such winds was demonstrated by a single set of sastrugi which pointed in the same direction (see Fig. 4).[12] Shackleton on his polar journey ascended the Beardmore outlet and for a like distance of two hundred miles over the inland-ice found strong winds blowing from the southerly quarter and sastrugi pointed in the same direction. David pushed northwestward from Ross Sea over the inland-ice to the south magnetic pole, crossing over a crest in the ice and descending on low grades during the last stage before reaching the pole. Here the same rule of distribution of currents applies,

[10] A. Wegener, "Med. om Grönland," Vol. 42, 1911, pp. 324–326.

[11] Wegener, "Med. om Grönland," Vol. 42, 1909, pp. 73–75.

[12] For this and other references to work published before 1910, see "Characteristics of Existing Glaciers," Chapters XIV.–XVI.

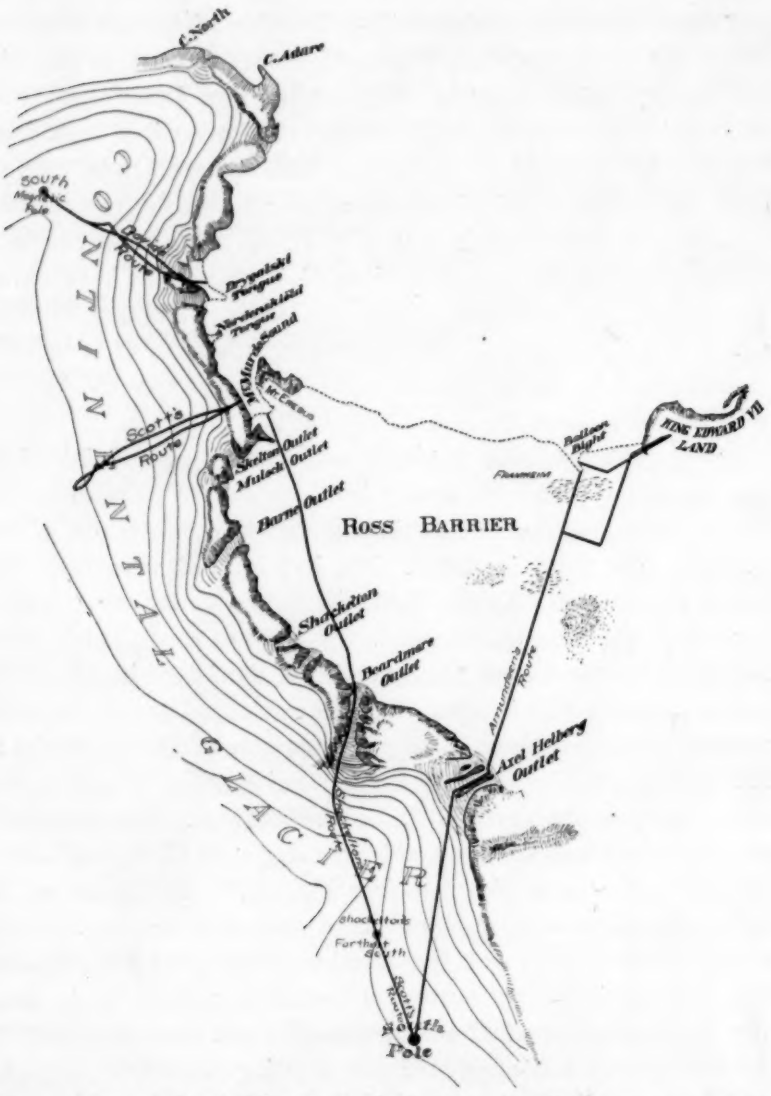


FIG. 4. Map of South Victoria land showing the sledge routes of Scott, Shackleton and David over the inland-ice.

for during the ascent he encountered northwest winds with sastrugi pointing toward the same quarter, but after passing the divide and on the down grade winds blew from behind—southeast. These observations were fully confirmed by the return journey

In Kaiser Wilhelm land also the report of von Drygalski shows that the prevailing winds blow downward off the inland-ice onto the sea and the shelf-ice in front, being deviated to the left—the prevailing strong winds are from the easterly quarter.

Later Confirmation.—Later data which bear upon the problem are derived from the Amundsen and the second Scott south polar expeditions, from the second German expedition to the Antarctic commanded by Filchner, and from the Australasian Antarctic expedition of 1911–14 under command of Dr., now Sir Douglas, Mawson. The route of Captain Amundsen passes through the mountain rampart which hems in the inland-ice, keeping a direction diagonal to it and for some distance after leaving the outlet behind taking a course near a high mountain range. The few data upon wind directions which he has jotted down in his narrative, appear to indicate local currents controlled by these mountains until he had reached the 88th parallel, where he entered an area of calms and light variable winds.[13] The second Scott expedition inasmuch as it followed the route of the earlier Shackleton expedition, has for the greater part of the distance, or until it entered the area of calms, served only to confirm the prevalence of outwardly flowing wind currents described by Shackleton.[14]

The recent Australasian expedition supplies evidence from a new quarter—the long coastal area near the Antarctic circle and to the westward of the Ross Sea, on which coast the inland-ice is not held in restraint by any barrier of mountains, as is the case in South Victoria Land. Along this coast, summer and winter alike, almost incessant storms blow off the ice onto the sea. These outwardly directed storm winds tend to keep the near sea area clear of pack-ice but offer great difficulties in the way of effecting a landing at all save those rare occasions when the force of the wind falls away.[15]

In Prince Regent Luitpold Land, where the later German expedition effected a landing upon the inland-ice—here likewise unconfined by a mountain wall and with partially detached shelf-ice in

[13] Roald Amundsen, "The South Pole," Vol. 2, 1913.

[14] "Scott's Last Expedition," Vol. 1, Chapters XVII–XIX.

[15] Sir Douglas Mawson, "Australasian Antarctic Expedition 1911–14," *Geogr. Jour.*, Vol. 44, 1914, pp. 257–286, maps and plates.

front—much the same conditions obtain, the wind blowing out to sea with velocities sometimes as high as 40 m.p.s.[16]

Outward Sweeping of the Surface Snow which Falls Over the Central Areas of the Ice Domes, and its Accumulation About Their Margins.

The Centrifugal Snow Broom.—What may be characterized as the centrifugal snow broom which sweeps out snow deposits from the central areas and collects them upon and about the margins of continental glaciers, is a necessary consequence of strong anticyclonic conditions; and its work is in evidence within all areas where inland-ice has been extensively explored.

From observations by Wegener, a wind velocity of 6–7 m.p.s. raises the snow lying upon the ground and sets it in motion along the surface at heights up to several decimeters (a foot or thereabouts). With wind velocities of 10–15 m.p.s (22.4–33.6 miles per hour) the migrating drift snow rises in a layer several meters in height and interferes seriously with seeing conditions. With velocities of 20 m.p.s. (44.7 miles per hour), the snow is carried to a height of 20 meters, or over sixty feet, and much higher in the lee of obstructions in its path.[17]

The Sweepings Below Outlets.—It is obvious that the results of snow drifting by centrifugal surface currents above inland-ice will be different according as the ice mass has been built up within a rampart of mountains (South Victoria Land and the greater part of Greenland), or as it has been allowed to shape itself independent of such retaining walls. In the former case the drift snow pours out along the courses of the outlet glaciers to form characteristic aprons at their bases,[18] or perhaps to produce definite fringing gla-

[16] "Deutsche Antarktische Expedition, Bericht über die Tätigkeit nach Verlassen von Südgeorgien," *Zeitsch. d. Gesellsch. f. Erdkunde z. Berlin,* 1913, p. 15; see also, *Kön. preusz. Meteorol. Institute,* Abh., Bd. 4, Heft II., p. 9.

[17] *Med. om Grönland,* Vol. 42, p. 345.

[18] In the light of observations by Scott, Shackleton and David in South Victoria Land, it seems probable that these apron-like snow deposits in the form of dry deltas are due largely if not wholly to this cause. Not only have explorers observed the rapid collection of the drift snow at the base of the Beardmore outlet, but this origin is probable for the reason that accord-

ciers such as have been described by Chamberlin[19] and Salisbury[20] from northwest Greenland, and by the Danes in northeast Greenland.[21]

Shackleton, who advanced over the inland-ice in his southern journey on a layer of granular surface snow, returned over a marble-like floor from which the snow had all been swept by the fierce blizzard encountered near his farthest south. On arriving at the Beardmore outlet, he found the lower forty miles of the stream buried deep under great drift accumulations. Scott on his last expedition was much less fortunate while on the plateau, and the burden of his diary is a prayer for strong wind to clear the surface. As is well known, he encountered heavy sweepings of powdery drift snow at the base of the Beardmore, both during his advance and on the return, and his floundering progress through this soft snow was a main contributing cause of the final disaster which overtook the expedition.

From what is known of the characters of freshly precipitated snow at different air temperatures, it is possible to rather definitely ascribe the enormous snow drifts which piled up for four consecutive days upon the Beardmore glacier apron as the *chasse neige* in process of melting as a result of adiabatic rise in temperature in descending currents. This snow, Captain Scott tells us, was the fine powdery type, though the temperature was phenomenally high ($+27° - 31°$ F.), stuck to hair and beard, and produced pools of water everywhere.[22] On the return the snow here was soft, loose and sandy, and sledge work was like "pulling over desert sand."[23]

Marginal Accretions of Snow.—Valuable new observations which bear strongly upon this point, have been supplied in the preliminary report upon the crossing of Greenland by Koch and

ance of *surface* level is generally observed to characterize the junctions of tributary with main glacier streams wherever snow drifting plays only a secondary rôle.

[19] *Jour. Geol.*, Vol. 3, 1895, p. 579.

[20] L. c., p. 886.

[21] Koch und Wegener, "Die glaciologischen Beobachtungen der Danmark-expedition," *Med. om Grönland*, Vol. 46, 1912, Chaps. VI.–VII., pls. and figs.

[22] "Scott's Last Expedition," Vol. 1, pp. 335–339.

[23] L. c., p. 396.

Wegener. They report almost continual storms in all save the highest section of their journey, the wind descending the slopes and filling the air with drift snow. Within the marginal portions of their section, it was established that the finely granular surface layer of snow is joined abruptly to a more coarsely crystalline subjacent layer and corresponds to the annual deposit. This layer was by a series of measurements shown to vary in thickness from 20 cm., or about eight inches, in the central portion, to one half meter (or about two and a half times that thickness) near the east coast, and a meter (or five times this thickness) near the west coast. Schematically represented with grossly exaggerated scales, this distribution is expressed in Fig. 5. It was further determined that the snow

FIG. 5. Diagram to illustrate the marginal thickening of annual snow deposit upon the Greenland continental glacier due to drifting on radial lines.

deposit at Borg, the winter station upon the inland-ice though relatively near its margin, was less than on the coast to the eastward.[24]

Still more recently has appeared the preliminary report of Mawson upon the Australasian Antarctic expedition, in which he tells us that at the winter station on the margin of the inland-ice, the winds which blew down slope and off shore raised "a sea of drifting snow which poured fluid-thick over the landscape."

> "For months the drifting snow never ceased, and intervals of many days together passed when it was impossible to see one's hand held at arm's length. The drift snow became charged with electricity and in the darkness of the winter night all pointed objects and often one's clothes, nose, and finger tips glowed with the pale blue light of St. Elmo's fire. . . . Such weather lasted almost nine months of the year. Even in the height of summer, blizzard followed blizzard in rapid succession."[25]

Where tongues of ice extended out to sea from the shore, snow collected upon them though the marginal slopes were swept free of it by the force of the blizzard.[26]

[24] A. Wegener, "Vorläufiger Bericht über die wissenschaftlichen Ergebnisse der Expedition," *Zeitsch. d. Gesell. f. Erdkunde z. Berlin*, 1914.

[25] Sir Douglas Mawson, "Australasian Antarctic Expedition, 1911–14," *Geogr. Jour.*, Vol. 44, 1914, pp. 269.

[26] Mawson, "The Home of the Blizzard," 1915, Vol. 2, p. 33.

Sudden Warming of the Air at the End of the Glacial Blizzard—Foehn Effect in Descending Currents.

Intensive Foehn Effective in Outlets.—This familiar foehn effect is so general a phenomenon about the margins of both the great continental glaciers that it has long been recognized.[27] The general rule holds that the temperature of the air rises as the blizzard is evolved.[28] Wherever a mountain rampart exists, the elevation of temperature becomes accentuated within the glacier outlets, and melting in Antarctica is almost unknown except under these conditions. An interesting example of this which has not before been emphasized, is supplied by Armitage, who on the first ascent of the Farrar outlet found a stream of water seven feet in width and nine inches deep flowing beside the ice.[29] The effect of similar currents of water was noted by David on his ascent to the plateau from McMurdo Sound. A remarkable instance, also, with long continuance of high temperature, is that above cited from Captain Scott's journal, while camped on the apron below the Beardmore outlet.

The Greenland Foehn.—The characteristic Greenland foehn has been subjected to a special study by Stade, the meteorologist of the Berlin Geographical Society's expedition to Greenland.[30] He finds that the temperature changes are much more pronounced during the winter season, the rise on March 5, 1893, having been 12° C. and probably much more within the space of a few minutes. Stade's conclusion is that these foehn winds are connected with low areas moving northward in the Davis Straits, the maximum of air temperature and the minimum of relative humidity corresponding either exactly or approximately with the minimum of pressure at the station. De Quervain's later studies would indicate that Stade's moving depressions may better be regarded as pulsations within a stationary low pressure area lying over Davis Straits and Baffin's

[27] See "Characteristics of Existing Glaciers," pp. 149–150, 268–271.

[28] Cf. Mawson, "The Home of the Blizzard."

[29] A. A. Armitage, "Two Years in the Antarctic," London, 1905, p.

[30] Dr. H. Stade, "Über Foehnerscheinungen an der Westküste Nordgrönlands und die Veränderung der Lufttemperatur und Feuchtigkeit mit der Höhe, Nach den Beobachtungen auf der Station Karajak, Grönland Expedition 1891–93," Vol. 2, 1897, pp. 501–533.

PROC. AMER. PHIL. SOC., LIV, 218 N, PRINTED AUG. 4, 1915.

Bay. It would then seem more in harmony with the facts to reverse this conception and assume that the low pressure area is stimulated to greater vigor by the arrival of the strong winds of the glacial blizzard over the inland-ice.

Foehn Level and Foehn Clouds on Greenland Coast.—In northeast Greenland the monumental investigations by Wegener furnish us with clearly defined results. In addition to full station weather observations collected for a period of two years at two neighboring stations—Pustervig, relatively near the inland-ice margin but within a canyon, and Danmarks-Haven, fifty miles further outward and upon the coast;[31] we have systematic observations with kites and captive balloons in ascents to heights generally of 1,500 meters and occasionally of 3,000 meters.[32] The results indicate that the larger weather disturbances are in the main controlled by the great high pressure area lying over the continent, that two strongly marked lower inversions in the atmosphere occur almost uniformly; the first within the lower 200 meters and explainable by surface radiation and latent heat of freezing and thawing, while the second lies between a thousand and fifteen hundred meters of altitude, at which level the great outward streaming from the inland-ice pours over the rock plateau to the westward of the station (average height of the plateau 800 meters). The most prevalent cloud form at the stations consists of a series of flat mushroom shapes in a succession of steps or stages located near the upper inversion level—on an average, 1,200 meters. These being clearly due to foehn conditions, they have by Wegener been given the name, "foehn clouds."

The twenty-three ascents of kites and balloons which were carried out at the time of more pronounced foehn, indicate that owing to the partial disappearance at such times of the lower cold moist layer, the temperature inversion of this lower layer is less pronounced and the temperature fall in the layers above it more pronounced, than at other times—in the most marked instances this fall

[31] A. Wegener, "Meteorologische Terminbeobachtungen am Danmarks-Haven, *Med. om Grönland*, Vol. 42, 1911, pp. 124–355. W. Brand und A. Wegener, "Meteorologische Beobachtungen der Station Pustervig," ibid., 1912, pp. 446–562.

[32] A. Wegener, "Drachen- und Fesselballonaufstiege aus gefuhrt auf der Danmark-Expedition 1906–08," ibid., 1909, pp. 1–75.

is super-adiabatic. The typical foehn cloud layer at 1,200 meters is also at such times much more marked, and up to this level the wind velocity falls off with altitude. Of the greatest significance were the results of ascents made at the time of easterly winds—always light; since these show that the easterly winds fade away below the altitude of 1,000 meters, at which level they become replaced by the westerly winds which are controlled by the anticyclones.[33]

Areas of Relative Calm and of Air Highly Charged with Moisture Corresponding to the Central Plains Upon the Ice Domes.

Few Early Data.—At the time "Existing Glaciers" was published, no observational evidence bearing upon this point was available from either of the large continental glaciers, since neither had been penetrated to the central area. Nansen's crossing of Greenland within its narrowed southern portion, had revealed an area of calm near the divide on his section, but it could not then be predicated that this represented more than the margin of the central ice plain. The most valuable evidence then available was derived from Northeast Land (Spitzbergen), which is covered by a dome of inland-ice about a hundred and eightly miles in diameter and between two thousand three thousand feet in altitude in the central area. This area of inland-ice had in 1873 been penetrated by A. E. Nordenskiöld and Palander, who several times observed the simultaneous fall of irregular ice-grains enveloped in water and of small snow-flakes either rounded or star-like, the ice-grains freezing immediately on falling and becoming attached to the hair or clothes, since the air temperature was $-4°$ to $-5°$.[34]

Recently Acquired Evidence from Antarctica.—During his penetration of the inland-ice area of Antarctica, Captain Amundsen entered near the 88th parallel, what he believed to be a region of permanent calm or of light winds and of generally clear weather. As evidence of this, the snow surface was smooth and with no in-

[33] A. Wegener, "Drachen- und Fesselballonaufstiege," *Med. om Grönl.*, Vol. 42, 1909, pp. 60–75.

[34] Cf. "Existing Glaciers," p. 277.

dication of drifting. To a depth of 2 meters no hard snow layers were encountered, so that the cutting of blocks (for guide cairns) was all but impossible. During the fortnight spent within this region the sky was clear with light winds, except on two days when there were snow flurries at intervals. The brightening after the snow was accompanied by such a high sun heat that even with most clothing removed the perspiration poured from the bodies of the men.[35]

Captain Scott, who entered the same general region about a month later, found conditions of atmosphere and snow which during the three weeks of his stay within it, agreed strikingly with those described by Amundsen. After passing the latitude 87½°, hardly a day passed that he did not jot down in his diary the fact of variable light winds and the noteworthy softness of the snow surface, several times expressing his opinion that the area is one of light winds. He was evidently puzzled by the appearance of the clouds, "which don't seem to come from anywhere, form and disperse without reason." Again he describes them as "coming and going overhead all day, drifting from the S. E., but constantly altering shape. Snow crystals falling all the time" (Vol. 1, p. 370). On January 19 on the return from the pole, he notes, "Snow clouds, looking very dense and spoiling the light, pass overhead from S., dropping very minute crystals; between showers the sun shows and the wind goes to the S. W."

Again and again he calls attention to the dampness and the chill in the air, so that when the temperature is observed, all are surprised that it is not lower. The sun was often shining through the snow mist, and bright sunlight and overcast sky interchanged with kaleidoscopic suddenness. Near the margins of this area snow blizzards were experienced, but in comparison with the Barrier blizzards Scott notes that the wind was surprisingly light. Temperatures rise after the blows. Within this central area the sastrugi are found in isolated areas, show cross directions and general lack of constancy. The snow got softer the farther they went to the southward, and it was soft below the surface also "as deep as you like to dig down." Yet with all the wind variations, there was evidently a preponderance of southerly and southeasterly winds. Like

[35] Roald Amundsen, "The South Pole," Vol. 2, Chapters XI.–XIII.

Amundsen, Scott noticed a slight descent toward the pole from latitude 89½°, which, taken in connection with Shackleton's observations, would indicate that a crest of the inland-ice lies to the westward of the routes.[36]

Recent Data from Greenland.—The account of de Quervain's transection of Greenland in 1912 in latitudes 66° to 70° N., affords strikingly similar pictures. Whereas for the first three weeks of the journey upon the inland-ice, or until the ascent had been made to the interior plain, the outward blowing winds had been so constant as to be depended upon in laying the course; shifting winds of light force were encountered upon the plateau, and when the grade had been reduced to 3″ of arc even west or northwest winds blew for short intervals. The air appeared to be strongly saturated with moisture, and at times only the heads of the party would be visible at moderate distances because of the bank of mist, and beards, chins, caps, etc., became frozen into solid masses of ice. Once over the divide, where the slope took on a descent of 8′ of arc, the wind blew strongly from the northwest.[37]

The expedition of Koch and Wegener which crossed Greenland in its widest section (in latitudes 71° to 79°), perhaps furnishes us with the most satisfactory evidence that has yet become available upon meteorological conditions above the central boss of a continental glacier; for the reason that no other expedition has penetrated so close to the heart of the area. From the preliminary report we learn that above the flat dome of the ice shield, an area of atmospheric calm was encountered and much mist, which in the morning was generally so dense as to hide the sun. The air was so supersaturated with moisture that the clothing was constantly wet and could be dried only occasionally and with much difficulty. Everywhere above the altitude of 2,000 meters the snow surface was granular and underlain by coarser grained material, though without hard separating crusts.[38]

Despite the supersaturation of the air and the frequent deposition of minute ice crystals from the clouds, it is pretty clear that if

[36] "Scott's Last Expedition," Vol. 1, pp. 363–383.

[37] A. de Quervain, "Quer durchs Grönlandeis," 1914, pp. 85–137.

[38] Alfred Wegener, "Vorläufiger Bericht über die wissenschaftlichen Ergebnisse der Expedition," *Zeitsch. d. Gesell. f. Erdk. z. Berlin,* 1914.

referred to the plateau surface, the peculiar shifting clouds so often observed by Scott and Amundsen are at a low level. The diurnal temperature chart published by de Quervain for his transection of Greenland, shows that radiation from the surface is apparently but little interfered with by clouds after the central plain has been reached. The abrupt change from this condition to one of small daily range of temperature, is found on both margins of the summit plain.

The Cirri Above and About the Existing Continental Glaciers.

The Earlier Data.—The relative abundance of cirrus and cirro-stratus clouds, not only above but about the margins of the continental glaciers, will be patent to any one who will read the lists of cloud observations which are published in the reports of the exploring expeditions.[39] In 1911 it was possible to cite the observation of Nansen, that during his crossing of the inland-ice though the sky was in the main clear, those clouds which were present were generally the cirri or some combination of these with cumuli or strati. From the Shackleton expedition in the Antarctic it was learned that the upper air currents near the winter station generally appeared to move in from the northwest quadrant and veer southerly as they advanced toward the pole. The "polar bands" or "Noah's Arc" clouds (cirro-strati) in general moved southerly, but to the west of the Ross Sea, the "polar bands" moved in from the north northeast or northeast veering round from the north. Thus, as a general rule, it would appear that in this region the upper currents carrying the cirri move roughly parallel to but in opposite direction from the stronger surface currents. In the same region additional evidence was derived from the behavior of the

[39] See, for example: "Wilkes Exploring Expedition (when off the Antarctic Continent)," Vol. XI., *Meteorology*, pp. 276–291; Mohn und Nansen, "Durchquerung von Grönland," *Pet. Mit.*, Ergänzungsh. 105, pp. 22–29; Duc d'Orleans, "Croisières océanographiques dans la mer du Gronland en 1905, Résultats Scientifiques," Bruxelles, 1907, pp. 52–67; Stade, "Grönland Expedition der Gesellschaft für Erdkunde," Vol. 2, pp. 417–441; Wegener, "Meteorologische Terminbeobachtungen," etc., *Med. om Grönland*, Vol. 42, 1911, pp. 202–311.

vapor cloud above Mt. Erebus, which starts from an elevation of nearly 14,000 feet.

Later Investigations.—In endeavoring to investigate further the movement of the cirri upon the borders of the inland-ice, the data supplied by the Greenland Expedition of the Berlin Geographical Society have been taken into consideration. Stade in his tabulated meteorological data at Station Karajak on the west coast, in some thirty-nine instances has supplied the direction of movement of the cirri observed. These I have plotted to form a wind-rose (Fig. 6),[40] which shows clearly the dominance of movements from the

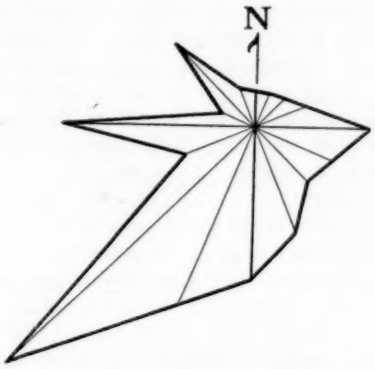


FIG. 6. Wind-rose for the cirri whose direction of motion was observed at station Karajac, West Greenland (several identified doubtfully as cirri are included).

southwest towards the northeast, or in other words in the general direction toward the interior region of the Greenland glacier.[41]

THE EVOLUTION OF THE GLACIAL BLIZZARD AND ITS ABRUPT TERMINATION IN FOEHN.

The Sequence of Events.—While there is apparently much in common between the Greenland and the Antarctic glacial blizzards,

[40] H. Stade, l. c., pp. 417–441.

[41] In central Europe Hesselberg has discovered a general correspondence between the drift of the cirri and that of the low pressure areas, but in view of the observations of de Quervain upon the stationary character of the depression over Baffin's Bay, it is unlikely that this conclusion can be applied to the borders of the inland-ice (Th. Hesselberg, "Ueber die Luftbewegung im Zirrusniveau und die Fortpflanzung der barometrischen Minima," *Beitr. z. Physik. d. fr. Atmosphäre,* Vol. 5, 1913, pp. 198–205.

we are indebted especially to Professor David, the meteorologist of the Shackleton expedition, for a careful study of the Antarctic type of blizzard as observed by him at the winter station of the expedition. I shall here cite my earlier summary of the sequence of events with some personal interpretations.[42]

"The sequence of events during a blizzard begins with gentle northerly winds which continue for a day or two during which temperatures are low. David has suggested that during this time air is flowing south to take the place of air whose volume has been reduced as a result of the heat abstracted from it on the ice surface. Then there follow two or three days of absolute calm, during which the temperature continues to fall. Still further cooled upon the ice surface, the air, a week or more after the calm begins, starts to move outward in all directions and so develops (on the edge of the barrier) a southeasterly blizzard. Simultaneously with this movement the steam cap over the volcano of Erebus, which normally indicates an upper current from the northwest, swings round to the north and takes on an accelerated movement, as though it were being drawn from that direction to supply air to the void resulting from the violent surface current toward that direction. Corresponding to the increased velocity, the normal foehn effect near the pole must be much increased as it is also on the descent of the surface current from the plateau. As soon as the warming of the polar air from this cause has become general, the high air pressure of the central area is automatically reduced, and thus the blizzard gradually brings about its own extinction. To the warming effect of the descending air current there is rather suddenly added the latent heat of condensation of the moisture when it is precipitated in the form of fine ice crystals within the air layers just above the snow-ice surface. The rather sudden termination of the blizzard may be thus in part explained. David has suggested that a 'hydraulic ram effect' may be induced in the air of the upper currents, since the steam clouds over Erebus, normally the antitrades, are temporarily reversed in direction at the termination of a blizzard, and for a short interval blow northward."

Source of the Precipitated Snow.—The actual initiation of the strong wind may begin very suddenly, as has been especially emphasized by Simpson[43] and even more strikingly brought out by Mawson.[44] Referring to the source of the moisture of the blizzard as the cirri, I stated in 1911:

"There is, however, the probability that in general this snow or ice is adiabatically melted and vaporized during its descent to the plateau, and subsequently congealed as it mixes with the cold air above the plateau

[42] "Characteristics of Existing Glaciers," pp. 269–270.
[43] "Scott's Last Expedition," Vol. 2, p. 325.
[44] Mawson, "The Home of the Blizzard," Vol. 1, Chap. VII.

surface. This would explain the clear skies which are so general over both Greenland and Antarctica during snows in the higher levels. It is of course true that the latent heat of fusion and vaporization of ice, abstracted as it is from the air during its descent within the eye of the anticyclone, will counteract to some extent the warming adiabatic effect; and it is not improbable that the long duration of Antarctic blizzards and their somewhat sudden terminations accompanied by snowfall are explained in part by the transformations of latent and sensible heat.

"Additional evidence for the continental and glacial rather than the polar nature of the Antarctic anticyclone is derived from the strong blizzards observed at the British winter quarters on McMurdo Sound. *Whereas the lighter gales came from the southeast and indicated a control by local conditions, a blizzard of the first magnitude was not thus influenced, and always swept down from the southwest—that is, from the high plateau, and not from the pole, since otherwise the earth's rotation would have given it an easterly direction.* When its powers begin to wane, it is once more controlled by local conditions and the wind again comes from the southeasterly quarter."

Amundsen's Meteorological Records at Framheim.—Hardly less significant were the directions of prevailing winds observed at Framheim, the winter quarters of the Norwegian Antarctic expedition of 1910–12, when the position of the station is considered in reference to areas of inland-ice and shelf-ice. The great dome of inland-ice of King Edward Land lies to the eastward and southeastward distant only about 115 miles, whereas that of South Victoria Land and its extension to the southeastward, lies a number of times that distance away to the southwestward and westward. Now it was found that easterly winds predominated (31.9 per cent. of the time), with southwesterly and southerly winds next in order (14.3 per cent. and 12.3 per cent. respectively). Southeasterly winds were especially rare, and as calms reigned for a fifth of the time (21.3 per cent.), the winds for four fifths of the period are those accounted for. Earth rotation should deviate original southwesterly winds into a southerly direction, and southeasterly to easterly.[44a]

Alternations of Calm and Gale.—The strophic characteristic of the glacial blizzard thus involves frequent alternation of calms with strong gales, and all systematic observations about the inland-ice reveal this characteristic. As already pointed out, the strophic quality is to be expected from the recurring disturbance of balance and later recovery in opposing forces (ante, p. 188). Below in tabu-

[44a] R. Amundsen, "The South Pole," Vol. 2, pp. 381–382.

lar form are set forth the percentage of calm days to all others as determined at several stations near the margin of inland-ice:

PERCENTAGE OF CALM DAYS TO ALL OTHERS.

	Per Cent.
Danmarks-Haven, Northeast Greenland[45]	26
Cape Adair, South Victoria Land[46]	45
Scott's First Base, South Victoria Land[47]	23
Cape Evans, South Victoria Land[48] (up to 4 miles per hr. 29.8 per cent.)	
Framheim, Whale's Bay[49] (up to 4 miles per hr. 42.2 per cent.)[48]	21.3

THE THEORY OF CIRCUM-POLAR WHIRLS VS. THE GLACIAL ANTICYCLONES.

Views of Ferrel and Hann.—From a theoretical view-point, the theory of circumpolar whirls first enunciated by the American meteorologist Ferrel, has been a most serious obstacle in the way of securing a clear conception concerning the air circulation above continental glaciers. Ferrel's theory assumed that strong westerly winds sweep about the geographic poles with increasing acceleration of velocity and corresponding centrifugal effect, producing polar areas of calm and of low barometer. Of the southern polar region, Hann stated as late as 1897:[50]

> "The whole Antarctic circum-polar area presents us, as already stated, with a vast cyclone, of which the center is at the pole, while the westerly winds circulate round it."

This view was of course largely speculative, and when Bernacchi of the "Southern Cross" expedition had brought out on the basis of observations at Cape Adare the evidence for anticyclonic conditions over the south polar regions, Hann cautiously qualified his earlier statements in the following manner:

[45] Wegener, "Med. om Grönl.," Vol. 42, pp. 325–326.

[46] Bernacchi, in Borchgrevinck, "First on the Antarctic Continent," p. 306.

[47] Shaw, "National Antarctic Expedition, 1901–1904, Meteorol.," Pt. I., 1908.

[48] Simpson, "Scott's Last Expedition," Vol. 2, p. 320.

[49] Amundsen, "The South Pole," Vol. 2, pp. 381–382.

[50] "Handbuch der Klimatologie," 2te aufl., Vol. 3, 1897, p. 543.

"As regards the Antarctic Anticyclone, I have certainly not expressed myself quite clearly in my 'Klimatologie,' as you very fairly point out.

"It is certain that an area of pressure, which is higher than that of the surrounding area, lying over a chilled continent, or over any considerable land area, can coexist with a great polar cyclone, for instance, round the South Pole. The very low temperature can produce in the lower strata of the atmosphere a pressure higher than its environments. The anticyclone, however, must be very shallow, and at a moderate elevation the ordinary circulation of the atmosphere must reëstablish itself. . . . It is just possible that further inland a slight increase of pressure might be observable. There is certainly no chance of the existence of a real continental anticyclone, inasmuch as at Cape Adare the barometer falls from summer to winter."[51]

The above and later qualified statements by Hann[52] fail to take proper recognition of the facts as known at the time, and in treatises on meteorology published within the last five years, the circum-polar whirls are still treated with slight qualifications of statement, and as though in harmony with observed facts.[53]

View of Meinardus.—Probably the fullest discussion of this subject is that of Meinardus in 1909, who is so firmly convinced that the anticyclonic conditions that were encoutered in Kaiser Wilhelm Land at the margin of the inland-ice, cannot have an upward extension beyond 2,000–3,000 meters, that he even prophesied for the interior portions of Antarctica a bare land area destitute of snow.[54] He says:

"The elevated parts of Antarctica above 2,000–3,000 meters extend into the great cyclone of the polar whirl and encounter westerly air currents during the entire year. With this verification, which also further can be supported by certain observations from the marginal region, there follows the conclusion *that the Antarctic anticyclone can in general be present as active element in the air circulation only in the lower parts of the South Polar region.* . . . At the sea level and on the borders of the inland-ice, that

[51] Letter written to Captain R. F. Scott in 1900, *The Antarctic Manual,* 1901, p. 34.

[52] "Lehrbuch der Meteorologie," 2te aufl., 1906, p. 345; Klimatologie, Vol. 1, 1908, p. 334.

[53] Moore, "Descriptive Meteorology," 1910, p. 141. Milham, "Meteorology," 1912, p. 162.

[54] W. Meinardus, "Meteorologische Ergebnisse der Winterstation der 'Gauss,' 1902–03, Deutsche Südpolar Expedition 1901–03," Vol. 3 (*Meteorol.,* I., Vol. 1), p. 332. (The italics are in the original, W. H. H.)

is, within the known coast areas, the anticyclonic conditions do not yet prevail."[55]

Referring to the observations by Captain Scott and by others upon the plateau back of the Admiralty Range in South Victoria Land, Meinardus is quick to seize upon the westerly winds which there prevail as evidence that the anticyclone has at these levels given place to the supposed overlying cyclones; failing utterly to note that the winds are here blowing directly down slope from the ice plateau—that is, radially.[56] Other statements in the report are likewise strikingly at variance with facts either known at the time or revealed by later exploration.

Objective Studies by Barkow in Antarctica.—The first opportunity to measure the upward extension of anticyclonic conditions over Antarctica, has been taken advantage of by Barkow, the meteorologist of the Second German Antarctic Expedition; who at the margin of the inland-ice of Prince Regent Luitpold Land (lat. 77° 45′ S., long. 34° 40′ W.) sent up pilot balloons, one on February 2, 1912, to the extreme elevation of 17,200 meters, or over 8 km. above the base of the stratosphere.[57] These observations disclose the fact that easterly and northeasterly winds prevailed at the time of observation in all levels *up to the ceiling of the troposphere,*[58] whereas with the beginning of the stratosphere, where at an elevation of 9,000 meters the wind turns suddenly through an angle of 180° and blows steadily from the southwest. If, as is probable, the margin of the continent corresponds to the margin of the inland-ice dome, these observations considered with due regard to the known deviation indicate an anticyclone fed by currents above the troposphere. Barkow calls attention to the speculations of Meinardus above referred to, and shows that they are controverted by the results of his observations.

[55] L. c., p. 333. Hardly in harmony with the facts known at the time, since easterly winds, and not westerly, are here the rule (cf. "Existing Glaciers," pp. 264–265, and ante, p. 197).

[56] L. c., p. 334.

[57] E. Barkow, "Vorläufiger Bericht über die meteorologischen Beobachtungen der deutschen antarktischen Expedition, 1911–12," *Ver. d. k. preusz. meteor. Inst.*, No. 265 (Abh., Vol. 4, No. 11), Berlin, 1913, pp. 7–11.

[58] The italics are mine.—W. H. H.

Barkow also carried out kite and balloon ascents, of which a proportionately slight per cent. only failed to show strong inversions of the lower atmosphere, these inversions being proportionately both strong and frequent during the winter season. The entire lower layer of 2,000 meters height was shown to have an average higher temperature than the lowermost layer, the temperature rise from the bottom being often as much as 10° C., and in one instance 19.5° C. In the spring season an alternation of inversions (Blätterstruktur) was observed.

De Quervain's Studies in Southwest Greenland.—No less decisive in showing the absence of polar whirls are conclusions to be drawn from observations on the borders of the inland-ice of Greenland. At a number of stations on the west and southwest coasts ranging between latitudes 64° and 69°, de Quervain and Stolberg in 1909 conducted ascents of pilot balloons during the spring and early summer, carrying their observations to extreme heights often in excess of 10,000 meters (6⅔ miles),[59] and in one instance of 16,000 meters. In 1912 Drs. Jost and Stolberg supplemented these observations by a second series carried out through the winter season, with results concerning which only a preliminary statement is as yet available.[60]

As has already been explained, the prevailing surface currents at these stations are controlled by the Greenland anticyclones and blow from the southeasterly quadrant, though with considerable modification by local conditions below the level of 1,000 meters. On the basis of his balloon observations, de Quervain has declared that "at least in greater elevations a polar whirl which is in any degree unified and connects the different low pressure regions of the circumpolar latitudes, can, for the time of our observations in Greenland and Iceland, not be thought of." This conclusion was later extended to the remaining portion of the year, as clearly stated in the preliminary announcement of the results of the later series of observations.

[59] A. de Quervain, "Gleichzeitige Pilotaufstiege in Westgrönland und Island, Veranstaltet durch die schweizerisch-deutschen Grönland-expedition und das dänische meteorologische Institut," *Beitr. z. Physik d. fr. Atmosphäre*, Vol. 5, 1913, pp. 132–158.

[60] A. de Quervain, "Quer durchs Grönlandeis, Die schweizerische Grönland-Expedition 1912–13," Munich, 1914, pp. 196, pls. 15, figs. 37 and map.

Distribution of Air Circulation in Successive Levels at the Inland-Ice Margin.—De Quervain's data upon wind direction are so vitally important as to merit some further consideration, particularly as regards the distribution of circulation within the different levels; and I have therefore used them to plot the wind-roses for each of the following ranges of altitude: 0–1,000 meters, 1,000–3,000 m., 3,000–5,000 m. (also separately 3,000–4,000 m. and 4,000–

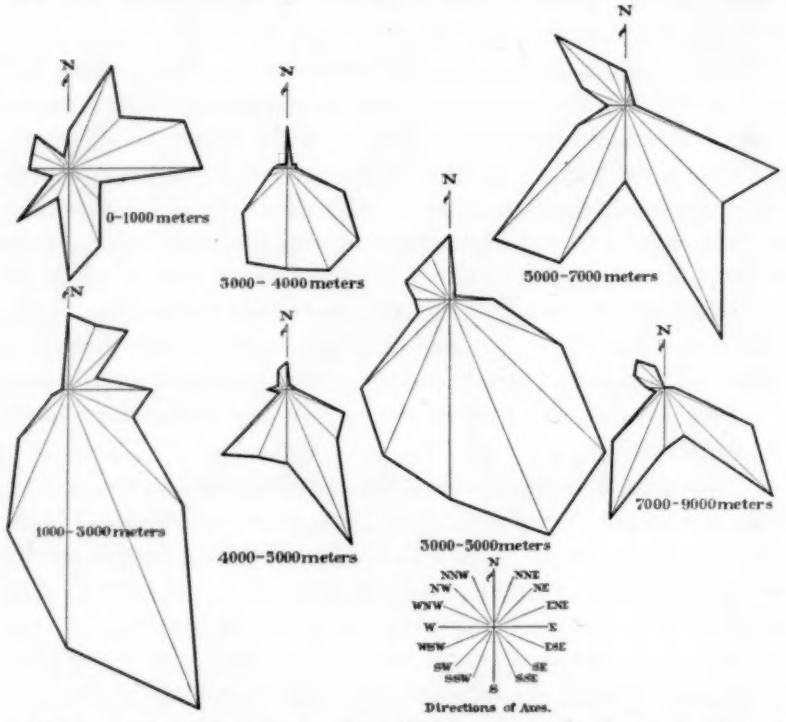


FIG. 7. Wind-roses to illustrate the prevailing winds between the levels indicated at stations on the west and southwest coast of Greenland (from data by de Quervain).

5,000 m.), 5,000–7,000 m., 7,000–9,000 m., and 9,000–11,000 m. For the lower levels between 40 and 58 ascents were available, whereas above 9,000 meters there were 13 and less. The wind-roses have been plotted with weighting for wind force (5 m.p.s. counting as one unit and the nearest unit being taken). Wind

velocities less than 5 m.p.s. were disregarded. The results, which are set forth in Fig. 7, show that below an altitude of 1,000 meters the wind, usually of low velocity, is notably variable and controlled by local conditions. At the level of 1,000 meters the outward flowing currents make their appearance in force and control the circulation up to an altitude of between four and five kilometers, above which level inward blowing currents from the southwesterly quadrant are of equal frequency and of about the same force as the outward blowing currents from the southeast. The clockwise deviation of currents in the anticyclone lead us to suppose that the outward blowing currents start from the interior in a more easterly direction, and that the inward blowing currents from the southwest are almost directly opposed, when they arrive in the interior.

The observations of Wegener made with kites and captive balloons in northeast Greenland, were not generally carried above an altitude of 2,000 meters, though in a few instances considerably higher. They agree among themselves and with those from west Greenland, in showing the presence of relatively variable winds up to about a thousand meters altitude, where these currents are replaced by the strong winds coming down the slope of the inland-ice and increasing in force and in clockwise deviation as one ascends to the limits of the observations. While they are therefore of great interest in revealing the strength and the upward extension of the glacial anticyclone, they have less direct bearing upon the question of circumpolar whirls.[61]

With the above data of Barkow and de Quervain before us, it seems that the time has arrived for laying the specter of the circumpolar whirl, and of returning to an objective basis of reasoning.

Winds About the Margin of the Inland-Ice as a Measure of the Vigor of the Antarctic Anticyclone.

The Zone of Control off "Wilkes Land."—The vigor of a glacial anticyclone may be measured, upon the one hand, by its extension upward from the glacier surface, as has been considered in the last section. Upon the other hand, it may be possible to use the exten-

[61] Wegener, "Drachen- und Fesselballonaufstiege," etc., pp. 55–59.

sion of its circulation outward beyond the glacier margin as an independent measure of its energy. This latter line of inquiry is a particularly fruitful one, for hitherto there has been a general tendency to delimit the zones of wind within the Southern ocean in terms of parallels of latitude.[62] Some years ago under the strong impression that the vigor of the Antarctic anticyclone should dominate within an extra-marginal zone upon the sea, I plotted the wind observations regularly made by the Wilkes Exploring Expedition;[63]

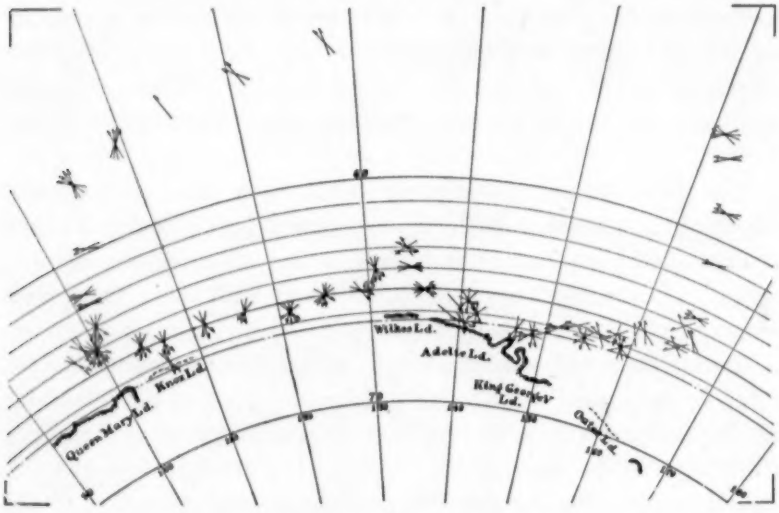


FIG. 8. Map of a portion of Antarctica on which the wind directions recorded by the Wilkes Exploring Expedition have been plotted, but with the margins of the continent corrected so as to accord with Mawson's map. *The arrows point to the wind quarter.*

but was puzzled to find that, whereas there was evident control by the anticyclone within a zone several degrees in width for all points to the westward of long. 150° E., this did not hold for the eastern portion of the route. Now that Mawson has definitely shown[64] Wilkes to have been in error in locating the margin of the continent for that portion of his route to the eastward of longitude 150° E., the apparent lack of harmony which I encountered is suffi-

[62] Cf., for example, Meinardus, l. c.

[63] "Wilkes's Exploring Expedition," Vol. 11 (Meteorology), pp. 272–296.

[64] *Geogr. Jour.*, Vol. 44 (September, 1914), pp. 257–286.

ciently explained. As will be readily seen by reference to Fig. 8, wherever Wilkes was within about three degrees, or some 200 miles, of the inland-ice, the prevailing westerly winds were replaced by southerly and southeasterly ones blowing off the ice. Mawson's own observations leave us in no doubt whatever that this rule of control holds for those margins of the continent which he explored to the eastward of longitude 150° E.

So apparent is the zone of control limited to a belt of 200 miles breadth, at the time of year when Wilkes made his observations, that the winds within and those without this zone for several degrees further, have been plotted in separate roses with results shown in Fig. 9.

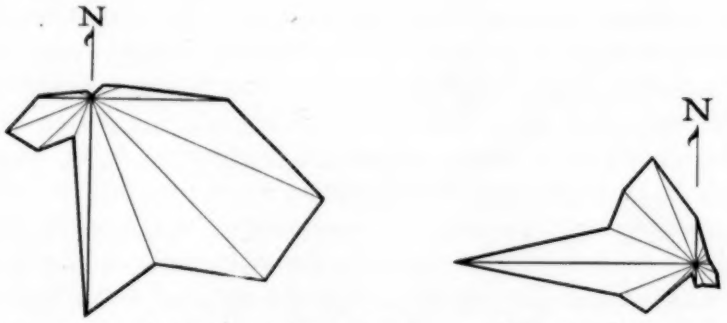


FIG. 9. At the left; wind-rose based upon Wilkes's observations at points distant less than 200 miles from the inland-ice; and, at the right; wind-rose for a zone several degrees in width lying immediately outside the zone of control.

Capt. Davis of the Australian Antarctic Expedition cites an interesting incident in the voyage of the *Aurora* off "Wilkes Land" which indicates he was at the margin of the zone of control.[64a]

The wind observations made by the "Challenger Expedition" at points which we now know to have been near the inland-ice,[65] are confirmation of this conclusion that the effect of the anticyclone extends outward from the margins. Had the observations been those of the first German expedition in 1901–03,[66] offer valuable

[64a] Home of the Blizzard, vol. 2, p. 40.

[65] Challenger Reports, Summary of Results, First part, chart 23.

[66] W. Meinardus, "Deutsche Südpol-Expedition 1901–03," Vol. 4 (Meteor., Vol. 2), pp. 312–319.

taken in the winter season, it is well nigh certain that the zone of control would have been found much wider.

Effect of the Greenland Anticyclone Upon Migrating Cyclonic Depressions.

Supposed Passage of Cyclones Across the Continental Glacier of Greenland.—A question which has been raised in connection with the Greenland continental glacier concerns the interaction of the glacial anticyclone and the migrating cyclones which have been supposed to move in toward the continent. Upon this assumption it might be held, upon the one hand, that the cyclone temporarily overwhelms the anticyclone, and "springing over it" continues upon its course; or, upon the other, that the cyclone is extinguished by the greater vigor of the anticyclone. Evidence which is now fast accumulating shows that, if the cyclones really advance toward the anticyclone, they are at least halted at its margin, and that both become parts of a system of exchanges planetary in its scope. There is, however, upon the assumption stated the possibility that an especially vigorous cyclone in approaching the Greenland coast during one of the weaker stages in the anticyclonic strophe, may make its influence felt not only upon the near side of the anticyclone but beyond it as well.

Nansen's Observations.—Nansen's conclusion after his crossing of Greenland was, that "the plateau seems to be too high and the air too cold to allow depressions or storm centers to pass across, though, nevertheless, our observations show that in several instances the depressions of Baffin's Bay, Davis Strait and Denmark Strait can make themselves felt in the very interior. We experienced, also, one instance of the crossing of a depression in the storm center which passed over us on September 8. This must have been, according to Professor Mohn, a secondary depression which lay over Baffin's Bay some days before."[67] This was, however, in latitude 64° where the inland-ice is extended southward in a relatively narrow tongue. According to de Quervain on but one occasion during the period of his observations on the Greenland west

[67] "First Crossing of Greenland," Vol. 2, p. 496.

coast, was there "an approximation to establishing" a relationship between an extremely rare northwest wind in the upper levels and a deep low area which lay over the Greenland Sea.[68]

The High Pressure Storms and the "Tauben" Depressions Registered at Danmarks-Haven.—In connection with the series of continuous meteorological observations made at Danmarks-Haven in northeast Greenland, Wegener found that while low pressure areas of normal character arrived at the station, they appeared to proceed from the area of the Greenland Sea; and in the absence of parallel observations, he assumed from the southward. The great storms came with an expansion of the high pressure area lying above the continent—so-called "high pressure storms." During the two years over which the observations extended, there passed over the station on two occasions (October and January), what Wegener has called "tauben"[69] depressions. On these occasions the barometer took a deep plunge with reverse movement, as it does during the passage of a tropical cyclone; yet there resulted neither precipitation of any kind nor any wind worthy of mention. This rather remarkable phenomenon Wegener has sought to explain as due to a cyclonic movement which has "sprung over" the anticyclone above the inland-ice, and in so doing has been robbed of its moisture,[70] and also, it would seem, of its circulation.

In view of all the facts, there is reason to doubt that "low" areas ever get across the larger domes of inland-ice; and the storm paths which Vincent has drawn across the continent of Greenland as though it were an expanse of ocean, should be accorded little weight, though it would seem that Wegener has been somewhat influenced by them.[71]

[68] De Quervain, "Gleichzeitige Pilotballonaufstiege, etc.," p. 146.

[69] Perhaps best translated, "barren," or "sterile."

[70] A. Wegener, "Meteorol. Terminbeob. am Danmarks-Haven," pp. 328, 332–334.

[71] E. Vincent, "Sur la marche des minima barométriques dans la région polaire arctique, du mois de septembre 1882 au mois d'août 1883," *Mem. de l'acad. Roy. de Belgique*, 1910.

THE FIXED LOW PRESSURE AREAS MARGINAL TO THE INLAND-ICE MASSES.

Antarctica.—The Filchner expedition seems to have established the fact that a fixed cyclonic depression lies off the border of the Antarctic continent covering the indentation of the Weddell Sea.[72] In the light of this discovery it now seems highly probably that a similar fixed depression lies above the indentation of the Ross Sea on the other side of the Antarctic regions and in nearly similar relationship to the inland-ice on either side.[73]

Greenland.—It is well known that a fixed low which is especially marked in the winter season lies off the southeast coast of Greenland, usually assumed to wrap itself about Cape Farewell in the form of a crescent, and extends northward into Davis Straits.[74] Recent studies of the free atmosphere by de Quervain at various points on the west and southwest coasts of Greenland indicate that a stationary area of low barometer (probably continuous with this) extends northward in Baffin's Bay as far at least as Disco Island.[75] The simultaneous studies carried out with pilot balloons at Akureyri in Iceland, indicate clearly that a stationary depression lies over the Greenland Sea to the northward of Iceland and between the Greenland and Norwegian coasts.[76] The Danes from the journeys of bottles set adrift during the expedition of 1906–08, determined that the currents within this sea are such as would indicate a stationary cyclone, since movements were southward along but off the Greenland coast until near the latitude of Iceland, where they are deflected eastward and later northward so as to follow the trend of the Norwegian coast.[77] Thus about both the glacial anticyclone

[72] L. c.

[73] See R. F. Scott, "Voyage of the *Discovery*," Vol. 2, p. 412; L. Bernacchi, "To the South Polar Regions, 1901," p. 298; W. S. Bruce, "Polar Explorations," New York, 1911, p. 187; Simpson, "Scott's Last Expedition," Vol. 2, p. 324.

[74] Cf., for example, Berghaus, "Atlas der Meteorologie," Pls. 33–34.

[75] A. de Quervain, "Gleichzeitige Pilotballonaufstiege in Westgrönland und Island," *Beiträge z. Physik. de Freien Atmosphäre*, Vol. 5, 1913, p. 145.

[76] de Quervain, l. c., p. 146.

[77] Alf. Trolle, "Danmark-Ekspeditionen til Gronlands Nordostkyst, 1906–08, under ledelse af L. Mylius-Erichsen," *Med. om Gronl.*, Vol. 41, 1913. See also, Sir John Murray and Dr. J. Hjort, "The Depths of the Ocean," London, 1912, p. 284.

groups it would now appear that the stationary "lows" are located where land barriers oppose a progressive movement.

The Rôle of the Glacial Anticyclones of High Latitudes in the General Air Circulation.

Circulation is Through Cyclones and Anticyclones, Not Merely Within Them.—In an earlier section it has been shown how the preconceived notion of a polar cyclone, the circumpolar whirl, has held back the advance of knowledge where the polar regions are concerned; and how this theory has now been effectually disposed of by the observations of de Quervain, Stolberg, Barkow and others.

The progressing cyclones within the atmosphere were by Ferrel assumed to be symmetrical in their distribution, with warm upward-moving central portions and cold marginal rims; to circulate the same body of air which repeatedly passes through certain paths; and to have their origin in areas of excessive local insolation. Instead of being symmetrical, as has now so generally been assumed, the study of isotherms in connection with cyclones has shown that these lines usually trend in the United States from southwest to northeast, crossing the cyclone by quite regular paths instead of being circular about its center. The evidence derived from international cloud observations would seem to show that the cyclone is a form of circulation *through which fresh portions of the atmosphere continue to stream;* and both cyclones and anticyclones are to be regarded as eddies which at the surface of the earth have each a hot and a cold side. The same air streams through both, its progress when projected upon the earth's surface being a sinuous line.

Belts of Progressing Cyclones and Anticyclones about the Antarctic Glacial Anticyclones.—The southern hemisphere, being less invaded by the continents, offers for the purposes of study some advantages on the side of relative simplicity, and it has in its meteorological aspects been recently comprehensively treated by Lockyer,[78] who has taken full account of the results of Antarctic

[78] W. J. S. Lockyer, "Southern Hemisphere Surface Air Circulation," etc., Solar Physics Committee under direction of Sir Norman Lockyer, London, 1910, pp. 109, pls. 15.

explorations and has endeavored to show the conjugate relationship of the Antarctic anticyclone area with successive zones of cyclones and anticyclones which migrate in an easterly direction around it. Thus it is found that between the low pressure zones lying within the tropics, and the fixed high pressure area above Antarctica, there are centered near the latitude of 40° S., a series of broad anticyclones which progress eastwardly and produce the effect of a zone of mean high pressure.[79] To the southward of this series of anticyclones and centered near the latitude of 60° S., there are a series of more vigorous cyclones of smaller diameter but progressing eastwardly at about the same angular rate. As we now know from later observations, the stationary cyclones lying over the Weddell and Ross Seas, establish further connection with the anticyclones above the Antarctic continent.

The cold outward flowing currents from the Antarctic continent upon reaching the zones of progressing cyclones are believed by Lockyer to ascend in them upon the west side, thus accounting for the cold western half of these cyclones near the ocean level.

The Australian Antarctic Expedition appears now to have supplied the evidence for such a rise of the air at the southern margin of the progressing cyclones near the borders of Adelie Land. As Mawson puts it:

> "It appeared as if we were situated on the battlefield, so to speak, of opposing forces. The pacific influence of the 'north' would hold sway for a few hours, a whole day, or even for a few days. Then the vast energies of the 'south' would rise to the bursting point and a 'through blizzard' would be the result."

At this junction zone of the glacial anticyclone with progressing cyclones, the air rises to produce rotating cumulus clouds, and it seems not unlikely that the interesting "whirlies" are connected with this uprise.[80]

The air having ascended in a cyclone on its journey northward toward the equator is believed next to pass downward through the progressing anticyclones to the northward, and to reach the ocean's surface as the warm current on the west side of these eddies.

[79] W. J. Humphreys, "On the Physics of the Atmosphere," *Jour. Franklin Inst.*, 1913, pp. 222–223.

[80] Mawson, "The Home of the Blizzard," Vol. 2, pp. 157–8 (fig.).

Mawson's demonstration through wireless communications that the hurricanes of Adelie Land preceded by some 48 hours the arrival of storms at the Australian south coast, would seem to support strongly this view (Fig. 10).[81]

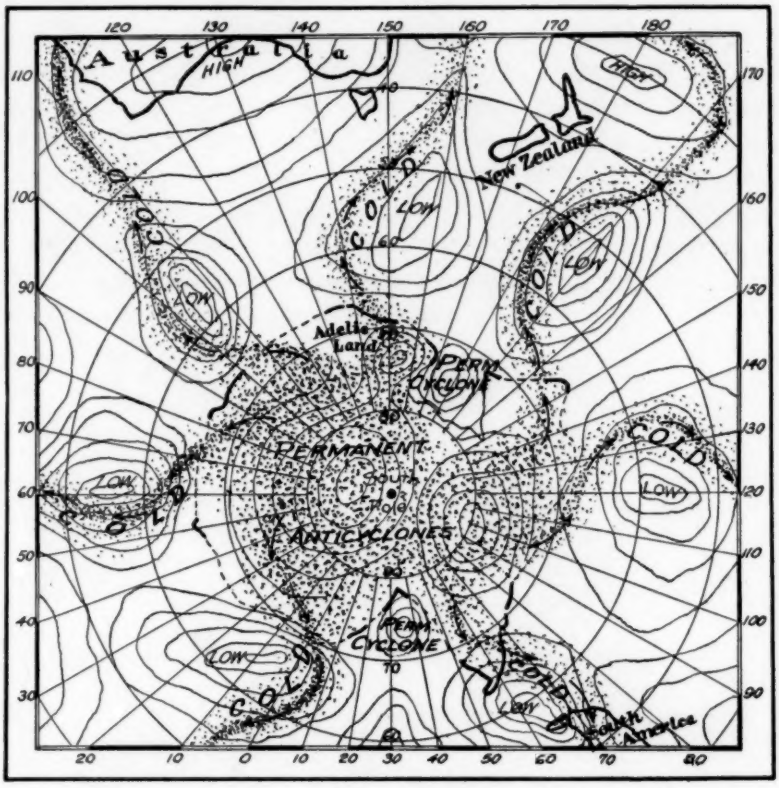
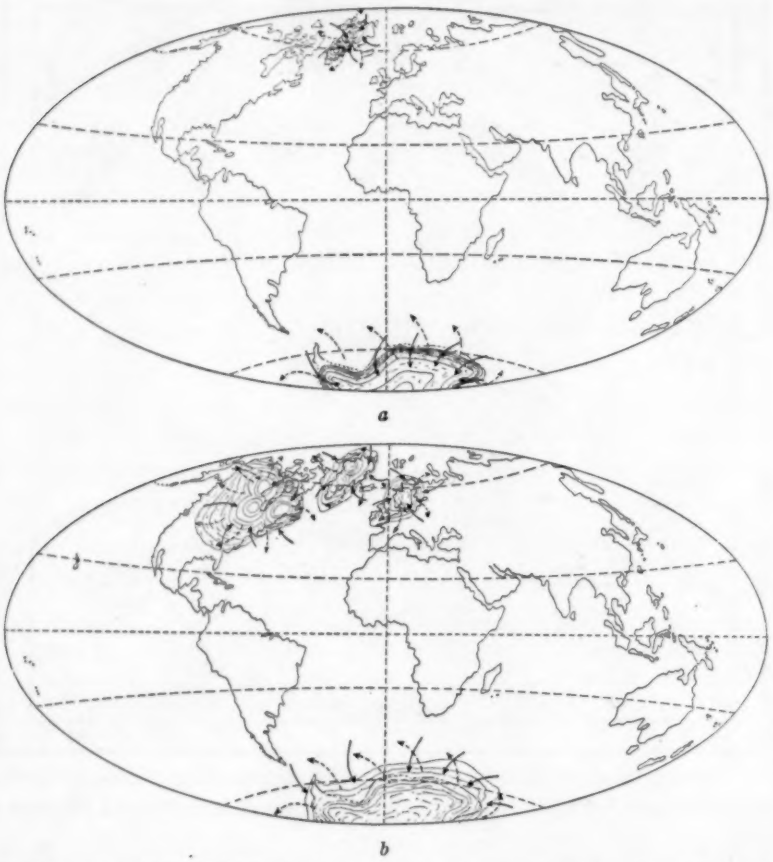


FIG. 10. Map to illustrate the prevailing atmospheric conditions to the southward of Australia (compiled from maps by Lockyer and Mawson).

The Rôle of the Glacial Anticyclones in the General Air Circulation to Draw Down the Air of the Upper Stratum in the Troposphere and to Direct it Equatorward.—From these geographical relationships it appears highly probable that the glacial anticyclones above the inland-ice masses stand in a definite conjugate relationship to stationary cyclones above embayments of the continent.

[81] Cf., also, "The Home of the Blizzard," Vol. 2, fig. opp. p. 141.

The glacial anticyclones of Greenland and Antarctica through drawing down of air from the upper levels and as a consequence of a throughout centrifugal surface circulation, are a very important factor in reversing the high poleward currents within high latitudes and directing them equatorward. The source of energy which



a

b

FIG. 11. (*a*) World map to show the present position of the earth's wind poles where the air of the upper stratum within the troposphere is in large part returned to the surface in glacial anticyclones. (*b*) World map to show the corresponding wind poles of the Pleistocene period.

maintains the whole system in motion, is of course the sun's heat concentrated within the tropics and in large measure absorbed over the continental glaciers (Fig. 11a). It is to be assumed that the

uplands of northeastern Siberia, the smaller masses of inland-ice within the Arctic region, and in fact any area where heat radiation is large, contribute in lesser measure to draw down the upper air currents and reverse their direction. It is the unhindered radiation of desert areas which is responsible for the anticyclonic conditions over them in the winter season. Abnormally high insolation in the summer season may, however, overbalance this effect and produce cyclonic effects. The moisture locked up in the ice needles of the cirri and related cloud forms above those areas of ocean where evaporation is large, is thus returned to the earth and especially within the glacial anticyclones. Of this moisture a portion is added to the glacier mass, but at the present time a much larger portion is blown off the glacier surface into the sea and so returned to its source in the waters of the ocean.

UNIVERSITY OF MICHIGAN,
ANN ARBOR,
March 12, 1915.

THE TEST OF A PURE SPECIES OF ŒNOTHERA.[1]

By BRADLEY MOORE DAVIS.

(*Read April 23, 1915.*)

There is probably no group of plants the genetic behavior of which has received so much study as the species of *Œnothera*. No group of plants is more prominently before the attention of experimental plant morphologists, and yet to many botanists it may appear that no group has yielded less of satisfaction. Among the workers with these forms there is the widest divergence of opinion, and of general conclusions there is little to show for the time that has passed since the appearance of "Die Mutationstheorie" in 1901 and the many years of study that De Vries devoted to the group previous to this date.

Can we find the point around which the difficulties cluster most thickly or from which the varied interpretations diverge most sharply? And, finding such a point can we formulate lines of experimentation that may clear the confusion of assumptions from which the various workers have proceeded to follow the lines of study that seemed to them to lead towards the light? To the writer the center of the difficulties lies in the fact that we have no accepted tests for the genetic purity of an *Œnothera* species.

By the genetic purity of a species we mean such a constitution of the germ plasm that a form is able to produce gametes of one type only for each sex. That is to say all male gametes of the form should have the same germinal constitution and thus be physiologically and morphologically equivalent, and all female gametes likewise should be of the same type. The male and female gametes may, however, differ in their respective effects upon the characters of a succeeding generation as shown by the marked differences exhibited by certain reciprocal crosses, for example, the reciprocals between *biennis* and *muricata*, or between *biennis* and *franciscana*

[1] Genetical Studies on Œnothera—VI.

(De Vries '13, Davis '14). The zygotes of a pure species must be uniform since the gametes of each sex are respectively similar, and a pure species, to employ that convenient expression of Bateson's, is therefore homozygous.

It has generally been held that no further proof of the genetic purity of a species is necessary than the established fact that it will "breed true," and I venture to believe that at present most workers among the œnotheras regard this test as entirely sufficient to establish the character of any material with which they work. If any line of *Œnothera* breeds true in large cultures it is confidently regarded as homozygous. Should a line fail to breed true to any considerable degree it is stamped as a hybrid if the investigator inclines towards the methods of analysis characteristic of the Mendelian school. Those who believe in mutations are so fully content with this test that to them a form need breed only reasonably true to pass as a pure species and the departures from the type, called mutations, are interpreted as due to modifications of the germ plasm not, however, the result of hybridism.

If a line of *Œnothera* fails to breed true to a very considerable degree and thus becomes suspected of a hybrid constitution, few workers would think of using it as favorable material for experimental studies to test the mutation theory. It is the lines which breed reasonably true that chiefly form the subjects of *Œnothera* discussions with reference to the theory of mutation. Such a line is the *Lamarckiana* of De Vries's cultures which when grown in large numbers in selfed families appears uniform except for certain small proportions of individuals, "mutants," which stand out clearly from the mass with distinctive characters that are readily recognized and may be clearly described. It is important to note that these new types are not connected by intergrading forms with the parent *Lamarckiana* and that they appear in successive generations of *Lamarckiana* with certain degrees of regularity.

More impressive than this history of *Lamarckiana* which has flowers open-pollinated, and consequently likely in Nature to have been crossed by insects, is the behavior reported for certain lines of *Œnothera* with flowers close-pollinated in the bud, a condition that obviously gives their own pollen the first chance to function and

thus greatly reduces the probabilities of cross-pollination. Such a plant is the *biennis* of Holland and other parts of Europe, a type of especial interest not only for its clear morphological characters but also because there is good reason for believing the line to be very old. This plant forms a large population in Holland with no near relatives and must have lived there for many years to have so thoroughly established itself. Indeed it seems probable that this *Œnothera,* the Dutch *biennis,* has come down to us essentially unchanged from the times of Linnæus who gave us its name. We know of no plant better representative of a species of *Œnothera* and we know of no *Œnothera* which better satisfies the generally accepted requirement that a species should "breed true."

Œnothera biennis L. in large cultures comes so true that hundreds of plants may be grown without finding a single departure from the type. Yet Stomps ('14) in large cultures of selfed lines from a single wild plant collected in 1905 discovered that this Dutch *biennis* throws occasional marked variants ("mutants") and he described a *biennis semi-gigas* with the triploid number of chromosomes (21), a dwarf type *biennis nanella,* and a color variety *biennis sulfurea* with pale yellow petals. De Vries ('15) at once took up the study of certain of the lines established by Stomps and grew cultures which totaled 8,500 plants. Among these were 4 plants of *biennis semi-gigas* about 0.05 per cent., 8 plants of *biennis nanella* about 0.1 per cent., and 27 plants of *biennis sulfurea* about 0.3 per cent. Since the percentages from *Lamarckiana* are for *semi-gigas* 0.3 per cent. and for nanella 1 to 2 per cent. it should be noted that with respect to these "mutants" *biennis* appears to be the more stable of the two species, although the color variety *biennis sulfurea* constitutes a new type of variant in experimental studies on œnotheras. A culture of over 1,000 plants from selfed seed of *biennis sulfurea,* all with pale yellow flowers, produced 2 dwarfs thus establishing a "double mutant" *O. biennis* mut. *sulfurea* mut. *nanella.*

As evidence for the mutation theory of De Vries this behavior of the Dutch *biennis* is to the writer much more trustworthy evidence than the behavior of *Lamarckiana* for the reason that the latter plant in his opinion does not have a clear record of long

existence, and probably is a form of comparatively recent origin. De Vries ('15, p. 173) has asserted again most vigorously his belief that *Lamarckiana* may be identified with a specimen from the United States collected by Michaux and now in the collections of the Museum d'Histoire Naturelle in Paris (De Vries, '14). With this view I cannot accord for reasons recently published (Davis, '15*a*). The showing of "mutants" from *Œnothera biennis* can hardly be considered very encouraging for the mutation theory of organic evolution when it is remembered that *biennis semi-gigas* is self sterile, that *biennis nanella* is frequently weakly or diseased, and that *biennis sulfurea* is clearly a retrogressive type having lost the power of producing normal yellow flowers.

Although *O. biennis* of all the œnotheras brought into the experimental garden still seems to me the form most free from suspicion of gametic impurity, nevertheless the line of Stomps has not, so far as we know, been subjected to the tests of a pure species summarized at the conclusion of this paper. De Vries ('15, p. 173) is mistaken in quoting me as conceding for this species a pure origin. I regard it simply as the safest material yet known on which to conduct studies in mutation, and with which other forms may be crossed to determine by the constitution of the F_1 hybrid generation whether or not their gametes are uniform. If in such a breeding test the F_1 progeny fall into two or more classes the assumption is justified that the form crossed with *biennis* must produce different classes of gametes. If the F_1 hybrid generation is uniform then it is clear that the functioning gametes male and female are respectively uniform. The fact that *Lamarckiana* crossed with *biennis* produces the "twin hybrids" *laeta* and *velutina* is, as has frequently been pointed out, one of the most important facts favoring the hybrid nature of *Lamarckiana*. It seems to me not improbable that other species of *Œnothera* will eventually be isolated more stable than the Dutch *biennis*.

Some exceedingly interesting observations have recently been reported by Bartlett ('15 *a, b, c*) on the behavior of certain small-flowered, self-pollinated American œnotheras. When grown in selfed lines these forms exhibit a behavior similar to that of *Lamarckiana* and *biennis* in throwing off in successive generations

certain new types. Thus from one of the species, *Œnothera stenomeres,* a mutant *gigas* appeared with the diploid number of chromosomes, and from another species, *O. Reynoldsii,* certain individuals throw from 60 per cent. to 80 per cent. of dwarfs. It is too early to discuss the remarkable peculiarities of these forms since the material of Bartlett has not yet been tested for its purity along the lines presently to be discussed. Bartlett regards the new types as "mutants" in the sense of De Vries. The important point for our consideration at present is the fact that these wild plants apparently continue to reproduce themselves from generation to generation even while giving rise to the new forms.

With respect to the taxonomic status of the plants which we have just considered the writer sees no alternative but their recognition as clear species. The *Lamarckiana* of De Vries, the *biennis* of Linnæus, and most of the types which Bartlett has segregated from the American wild œnotheras breed true as to the mass of their progeny. What further qualifications can taxonomy in reason demand? Species they are by virtue of their morphology and by the test of the experimental garden which shows their characters to be stable to an extent that renders it certain that each line self-pollinated will maintain itself unchanged, indefinitely as far as we can see, through successive generations.

The argument that will follow as to the genetic constitution of these species of *Œnothera* does not in the least affect the matter of their recognition in taxonomy as species. It may be prefaced by two questions stated as follows: Are the types pure species, homozygous because the plants develop male gametes of one type only and because their female gametes have a uniform germinal constitution? Or, are the types heterozygous developing different types of male gametes and different types of female; briefly expressed have they in some degree a hybrid constitution?

But it will at once be asked, how can a species be hybrid even to a small degree and yet breed as true as do these forms under consideration? Where in their behavior is evidence of a hybrid constitution such as might appear in the splitting off of numerous different forms varying from the parent type, some in small degrees and some in larger degrees? Where is evidence of an orderly segre-

gation of characters such as has been demonstrated by the Mendelian research of recent years? To these questions it must frankly be answered that only here and there are glimpses of situations which may possibly be interpreted in terms of Mendelian analysis. For example the characters of the "mutants" are frequently clearly retrogressive which indicates that gametes are formed lacking certain factors and suggests phenomena characteristic of segregation from heterozygous stock and very common in Mendelian behavior. Again, the repetition of the same "mutants" in a series of generations suggests a mechanism of precision such as we have come to associate with Mendelian inheritance. It is not, however, my purpose to argue at present this phase of the discussion for the experimental data before us is not in such shape that it can be handled to the best advantage. We admit that the "mutants" themselves do not establish their parents as in their nature hybrids. If they did there would of course be no discussion.

Under two conditions and apparently two only can a heterozygous species be conceived as breeding true.

First, if of the varied possible types of gametes *only such unite and produce fertile zygotes as will perpetuate the same germinal constitution as the parent,* then from such zygotes a heterozygous line might continue indefinitely as an impure or hybrid species. Under such conditions gametes which might in varied combinations give a series of different forms (segregates) are either not matured or if matured fail to function. Some degree of pollen and ovule sterility must be expected as the result of such conditions.

Second, if of a varied assortment of zygotes formed by the union of different types of gametes, *only those develop which have the germinal constitution of the parent* then again a heterozygous line might continue indefinitely and constitute a species, although impure or hybrid in its nature. Since all of the zygotes which result from other combinations of gametes either die or fail to develop beyond some early stage in the life history this condition would result in some degree of seed sterility or in the production of weak plants that must soon perish.

Now the œnotheras as a group exhibit a very remarkable amount of pollen sterility and also a high degree of ovule abortion, and

these plants frequently give extraordinarily low yields of fertile seeds although seed-like structures may be formed in abundance. These facts we are just beginning to appreciate as offering problems for study. They seem to the writer of vital importance to the discussion of *Œnothera* genetics, facts which the Mutationists cannot ignore and behind which the Mendelians can maintain at present a very strong defence for their interpretations of the peculiarities of *Œnothera* behavior.

With respect to pollen sterility it has for many years been known that *Lamarckiana* and other species of *Œnothera* present large proportions of abortive pollen grains. Bateson (1902) early seized on the point and suggested that the high degree of pollen abortion in *Lamarckiana* indicated a hybrid plant exhibiting partial sterility. Geerts ('09) in an excellent account of the cytology of *Lamarckina* showed that approximately one half of the pollen grains fail to mature and that one half of the ovules fail to develop embryo sacs. Geerts ('09, p. 89) also made an examination of more than one hundred species of the Onagraceæ, giving us the conditions of pollen and ovulue fertility represented in some fifteen genera. He found generally in species of *Œnothera* and allied genera a degree of sterility similar to that in *Œnothera Lamarckiana,* about 50 per cent. for both pollen and ovules. On the other hand certain species of *Jussieua, Zauschneria, Epilobium, Boisduvalia* and *Lopezia* are wholly or almost wholly fertile.

My own examination of conditions in the material of *Œnothera* with which in recent years I have worked has shown some remarkable differences in the amount of pollen and seed sterility. Such close pollinated types as the Dutch *biennis,* the Dutch *muricata,* American *muricata* (from Woods Hole), *Tracyi,* and a number of American small-flowered species (for example *biennis* A and *biennis* D of my cultures (Davis, '11, p. 197 and '12, p. 385)), have very large amounts of sterile pollen. In the case of the Dutch *muricata* much more than 50 per cent. of the pollen has been sterile. Yet these are types which by virtue of their long history of close pollination might be expected to be among the purest of the species. On the other hand the race *grandiflora* B (Davis, '11, p. 203), and the western species *franciscana* and *venusta,* all open pollinated

species show hardly more than a trace of pollen abortion, and *Jamesii* from Texas only a small amount of sterile pollen. I have this winter tested the seed fertility of some of these species by germinating the seeds in Petri dishes after the method recently described (Davis, '15*b*). The Dutch *biennis* gave a germination of about 96 per cent., the Dutch *muricata* about 72 per cent., *grandiflora* B about 95 per cent., *franciscana* about 61 per cent., *venusta* about 87 per cent., and *Jamesii* about 91 per cent.

It is interesting to note in the above list that the Dutch *biennis* with its very high percentage of fertile seeds (96 per cent.) has extensive pollen abortion and the Dutch *muricata* with seed germination of about 72 per cent. has an even lower degree of pollen sterility. On the other hand there are species of *Œnothera* with both high seed and pollen fertility as illustrated by some races of *grandiflora, venusta* and *Jamesii*. I was especially interested in the conditions shown by my race *grandiflora* B with its almost perfect fertility both as to pollen and seeds. This race isolated from a collection of mixed seeds gathered by Tracy in 1907 at Dixie Landing, Alabama, has always seemed to me to present a type of unusual purity. The line was started in 1908 by a cross of two similar plants (Davis, '11, p. 203) representing the broader-leaved forms of *grandiflora* that were present at Dixie Landing and I have grown in small cultures several generations of the plant without noting departures from the type. I cannot accept the criticism of De Vries ('14, p. 348) that my race *grandiflora* B is impure because from the same collection of mixed seeds of Tracy's he obtained a diversified culture as I also reported (Davis, '11, p. 203) when the line was first isolated, and because De Vries and Bartlett found the Dixie Landing station "desolate" five years after the visit of Tracy. This type may prove to be nearer to the desired pure species than the Dutch *biennis*.

Jeffrey in recent papers ('14*a*, '14*b*, '15) has taken the position "that in good species the spores or pollen is invariably perfect morphologically" and from this standpoint refuses to consider *Lamarckiana* and other œnotheras as suitable material on which to base experimental studies on mutations. To him the mere presence of

abortive pollen suffices to stamp a form as hybrid in character. This represents an extreme view which in consideration of our ignorance of possible physiological reasons for pollen sterility can at present scarcely be claimed as more than an hypothesis. For the œnotheras we are greatly in need of cytological and physiological studies on pollen sterility more detailed than the incidental observations that have so far been published.

With respect to the abortion of ovules among the œnotheras our information is practically confined to the observations of Geerts ('09), mentioned above. It appears that in *O. Lamarckiana* and a number of other species only about 50 per cent. of the ovules develop embryo sacs. Other species also show varying degrees of ovule abortion. The ovules that fail to mature are represented in the capsules by a fine light brown powder known to all who work with œnotheras. Such powder is very common in the capsules of various species and their hybrids, and it seems probable that ovule sterility is as widespread in this group of plants as is the degeneration of the pollen. As in the case of pollen sterility we do not know to what extent physiological conditions may also be responsible for the abortion of ovules.

Pollen and ovule sterility involve of course the elimination from the life history of immense numbers of gametes and raise the following questions. Can it be that this elimination throws out of the life cycle types of gametes with germinal constitutions different from the gametes that matured and that function? It is possible that some of the *Œnotheras* species, in hybrid condition, regularly mature for the most part particular classes of gametes which in conjugation will perpetuate the genetic line of the parent plant? Gametes even when normally developed may still not function as when pollen grains fail to germinate upon the stigma because its secretions are not suitable. It must also be borne in mind that there are yet other phases of the life history when gametes may become ineffective as through failure to conjugate or because of a high mortality among zygotes, embryos, or young plants; such forms of infertility are expressed in sterile seeds or in weak offspring which never mature. Possibly the so-called "mutants" arise when unusual gametes from hybrids, occasionally surviving the ex-

tensive process of degeneration, form zygotes also able to survive and to develop plants diverging from the parents.

The subject of seed sterility among the œnotheras has scarcely been touched by the students of the group and yet it seems likely to become a factor of prime importance in its bearings on the problems of *Œnothera* genetics. Any worker among these plants shortly becomes aware of the fact that very many of the seed-like structures which he sows fail to germinate even though seed pans are kept for many weeks. De Vries makes frequent reference to the facts of seed sterility and the writer has in recent years recorded the number of seeds sown in cultures and the number of seedlings that develop. The results are most surprising and must have significance although what that may be remains for the future to disclose. A line of research has opened before us that will demand a special technique, for it is not enough to know merely that certain proportions of the seeds germinate within the time practicable for keeping seed pans under observation.

Seed-like structures sown on the earth are obviously lost for further enquiry as to the facts of their viability; a proportion of seedlings appear but as for the residue, that cannot be examined. The residue may contain viable seeds the germination of which is delayed, or it may consist wholly of sterile structures. We must develop methods that will ensure the rapid and complete germination of seeds in convenient receptacles such that the residue of sterile structures may be left for study after the seedlings have been removed and set in the earth. By such methods cultures of *Œnothera* may be grown in which one may feel confident that all of the viable seeds have germinated since by an examination of the residue it may be determined whether or not the seed-like structures have embryos. It is probably safe to say that no culture of *Œnothera* has as yet been described in which we may feel certain that the progeny of the sowing is complete. During the past winter I have tested the percentage of seed fertility in some fifty species and hybrids of *Œnothera* germinating the seeds on pads of wet filter paper in Petri dishes. With this method may advantageously be combined the clever practical suggestion of De Vries ('15, p. 190) of forcing water into wet seeds by air pressure thereby greatly

hastening their germination. A description of a method of seed germination which will, I think, prove to be satisfactory in genetical work on *Œnothera* may be found in the Proceedings of the National Academy of Sciences, Vol. I., p. 360, 1915.

The first investigator to make use of the facts of seed sterility in suggesting Mendelian interpretations of the behavior of *Lamarckiana* and certain *Œnothera* crosses has been Renner ('14) and his line of investigation has opened a field of research and speculation that must be reckoned with in the future. Renner has studied the seed structure in *Lamarckiana, biennis* and *muricata,* and in certain crosses among these forms. His conclusion on the genotype of *Lamarckiana* will illustrate the principles underlying the method of attack. Since *Lamarckiana* when crossed with *biennis* and certain other species gives in the F_1 hybrid generation the twin hybrids *læta* and *velutina* it may be assumed to develop two classes of gametes which function. These may be spoken of as the *læta* and *velutina* gametes and are produced in about equal numbers. When *Lamarckiana* is self-pollinated the *læta* and *velutina* gametes may combine in proportions to give 1 pure *læta*: 2 *læta-velutina*: 1 pure *velutina*. It is a fact that more than one half of the seeds of *Lamarckiana* fail to develop normal embryos and Renner concludes that these sterile seeds represent zygotes homozygous respectively for the *læta* and *velutina* factors. The fertile seeds develop from the heterozygotes with both *læta* and *velutina* factors combined and this combination gives the characters of *Lamarckiana*. *Œnothera Lamarckiana* may thus be an impure or heterozygous species breeding true because of the death of such zygotes as carry the factors for *læta* and *velutina* in homozygous conditions. This simple Mendelian explanation of the behavior of *Lamarckiana* points a line of interpretation and study certain to be fruitful in *Œnothera* research.

Among hybrids of *Œnothera* the seed sterility sometimes runs extraordinarily high. The most remarkable illustrations of this fact so far known appear in the second generations of crosses involving the Dutch *biennis* and the Dutch *muricata* which exhibit certain remarkable morphological peculiarities discovered and described by De Vries ('13). First generation hybrids of reciprocal crosses

between these species grown by the writer in 1913 gave data on seed germination in the earth as presented in Table I.

TABLE I.

F_1 Hybrids of Reciprocal Crosses between *O. biennis* and *O. muricata*.

Culture.	Cross.	Seeds Sown.	Sown in	Seedlings.	Germination.	Duration of Experiment.
13.33	F^1 *biennis* × *muricata*	673	Earth	139	20%	6 weeks
13.34	F^1 *muricata* × *biennis*	153	Earth	97	63%	7 weeks

It is probable from my experience with other species crosses that the viability of the seeds of these F_1 hybrids is really high and that the relatively low percentages recorded above are due to de-

TABLE II.

F_2 Hybrids of Reciprocal Crosses between *O. biennis* and *O. muricata*, Including Certain Double Reciprocals, Sesquireciprocals, and Iterative Hybrids.

Culture.	Cross.	Seeds Sown.	Sown in	Seedlings.	Germination.	Duration of Experiment.
14.41 (13.33a)	F_2, *biennis* × *muricata*	466	Earth	8	1.7%	9 weeks.
14.42 (13.34c)	F_2, *muricata* × *biennis*	205	Earth	35	12%	9 weeks.
14.43 (13.33a × 13.34)	double reciprocal $(b \times m) \times (m \times b)$	73	Earth	8	11%	9 weeks.
15.31 (14.33 × 14.16)	sesquireciprocal $(b \times m) \times b$	267	Earth	25	9%	9 weeks.
*15.31 (14.33 × 14.16)	sesquireciprocal $(b \times m) \times b$	282	Petri dish	132	46%	6 weeks.
15.32 (14.16 × 14.33)	iterative $b \times (b \times m)$	22	Earth	1	4%	9 weeks.
15.33 (14.33 × 14.20)	iterative $(b \times m) \times m$	212	Earth	2	0.9%	9 weeks.
*15.33 (14.33 × 14.20)	iterative $(b \times m) \times m$	292	Petri dish	42	14%	7 weeks.
15.34 (14.34 × 14.16)	iterative $(m \times b) \times b$	217	Earth	47	21%	9 weeks.
*15.34 (14.34 × 14.16)	iterative $(m \times b) \times b$	373	Petri dish	73	19%	4 weeks.
15.35 (14.34 × 14.20)	sesquireciprocal $(m \times b) \times m$	246	Earth	43	17%	9 weeks.
*15.35 (14.34 × 14.20)	sesquireciprocal $(m \times b) \times m$	498	Petri dish	198	39%	7 weeks.
15.36 (14.20 × 14.34)	iterative $m \times (m \times b)$	198	Earth	51	25%	9 weeks.

layed germinations. But the figures for germination in the earth of F_2 hybrids and of double reciprocals, sesquireciprocals, and iter-

ative hybrids are most surprising in the degree of sterility or delayed germination shown. They are given in Table II., where are also presented the records of four cultures sown in Petri dishes in which the germination was complete as proved by an examination of the residue.

A comparison in Table II. of the record for culture 15.31 with *15.31, 15.33 with *15.33, and 15.35 with *15.35 will illustrate the gain in germination that may come through sowing seeds in Petri dishes. The percentages of germination presented above for the hybrids of *biennis* and *muricata* must not be regarded as expressing exactly the degree of seed fertility under the conditions of the experiments since with the harvests of seed are frequently found very many structures too large to be abortive ovules and too small to be counted as "seeds" in the sense of falling within the limits of seed size. These structures are probably undeveloped seeds but only a microscopical examination can determine this point; if so, their presence of course always lowers the percentage of zygotes capable of giving progeny.

Bearing in mind the fact that pollen sterility in *biennis* and *muricata* is 50 per cent. or more and that pollen abortion in the F_1 hybrids is very much higher (in fact very little good pollen is produced) the total amount of sterility both gametic and zygotic is simply amazing. Under such conditions how can the behavior of these hybrids be looked upon as indicative of anything but a most unusual situation, in itself very interesting, but far beyond the expectations of normal hybrid behavior. This remarkable degree of sterility among the hybrids of *biennis* and *muricata* is perhaps extreme for the œnotheras, but it serves to illustrate conditions extensively present in the writer's experience and doubtless also in the experience of others.

De Vries has described the hybrids between *biennis* and *muricata* as breeding approximately true which in the main has also been my observation. Apparently largely upon this behavior and that of certain other crosses he has reached the conclusion that hybrids between species of *Œnothera* are stable. In this opinion of De Vries I cannot agree for my crosses between *grandiflora* and certain small-flowered American species (Davis, '12 and '13), and between

biennis and *franciscana* have in the F_2 generations given abundant evidence of that extensive variation interpreted as segregation. I believe that the apparent stability of the very small progenies produced by hybrids of *biennis* and *muricata* simply means that the remarkably high mortality among gametes and zygotes of these hybrids, or the delayed germination of their seeds, has prevented the appearance in our cultures of the diverse types which theoretically would be expected. Any general conclusions on genetic behavior in the œnotheras which fails to take into account the phenomena of sterility rests upon insecure foundations.

It is true that we do not know to what extent physiological factors may affect seed sterility as well as pollen and ovule abortion. Nevertheless a main fact is clear, namely that seed sterility eliminates in certain *Œnothera* species and hybrids immense numbers of zygotes which fail to develop seeds. And, furthermore, we know for œnotheras that large classes of weak offspring are sometimes produced that are unable to reach maturity. Seedlings with white or yellow cotyledons, which quickly die, are not uncommon in my experience with *Œnothera* cultures; in certain cases they have appeared in very large numbers (Davis, '11, p. 222) and probably have important genetical significance. This situation in *Œnothera* finds a close parallel in the behavior recorded for a number of animals and plants. Thus Baur's "golden" variety of *Antirrhinum* is an impure or heterozygous form which besides reproducing itself throws a class of normal green plants and a class represented by weak yellow seedlings that shortly die. The yellow mice studied by Castle and Little although interbred always remain impure giving progeny heterozygous for yellow because of the death of zygotes with a double dose of the factor for yellow. A dwarf wheat isolated by Vilmorin cannot be fixed since it always remains heterozygous throwing talls but never producing homozygous dwarfs. The white female form of the clover butterfly, *Colias,* was found by Gerould always to give yellow offspring either because of the failure of the gametes carrying white to conjugate or because zygotes homozygous for white fail to develop. A form of *Drosophila* characterized by confluent wings has been found by Metz only in the heterozygous condition, always throwing normals and never breed-

ing true; flies homozygous for confluent wings are apparently not viable. Is it not possible that parallel or related phenomena are extensively present among the œnotheras? The mortality as shown by sterile seeds may indicate the elimination of large groups of forms divergent from the parent types, and some of the curious dwarfs and aberrant plants which again and again have been reported in *Œnothera* lines may be from zygotes barely able to survive the death-producing conditions that eliminate so many of their companions.

So far we have considered evidence chiefly of a negative character for the contention that many of the species of *Œnothera* are impure or hybrid species. We have tried to show that pollen, ovule, and seed sterility must all be reckoned with as conditions which may eliminate Mendelian classes of gametes and hold a line to a history of relatively true breeding even though the stream of germ plasm remain heterozygous or impure in character. The natural corollary of such behavior, if proven, might be the interpretation of so-called "mutants" as segregates from a hybrid stock that were able to survive the destruction meted out by conditions that produce sterility. To what extent the causes of sterility may lie in the history of gametogenesis or may be due to unfortunate combinations of gametes, or to what extent sterility is the result of physiological factors, these are problems that lie before us.

Let us now examine some positive evidence that certain species of *Œnothera* do form distinct classes of gametes and in consequence seem likely to be heterozygous in their constitution. That which first demands attention is the situation discovered by De Vries in certain first generation hybrids and by him named "twin hybrids." We have already referred to this phenomenon first described by De Vries ('07) for the behavior of *Lamarckiana* which as a pollen parent in crosses with other species of *Œnothera* gives not uniform F_1 generations but the two types *læta* and *velutina* (twin hybrids), produced in about equal numbers. Certain "mutants" of *Lamarckiana* also give twin hybrids under the same conditions as those produced by *Lamarckiana*. The behavior is so exact that the simplest hypothesis must suppose that *Lamarckiana* and these "mutants" form two classes of gametes which are fertile in these par-

ticular crosses. De Vries ('09) has also described "triple hybrids" when the "mutants" *scintillans* and *lata* are pollinated by such species as produce the twin hybrids from *Lamarckiana*. In such cases two of the forms have the characters of *læta* and *velutina* combined with those of the other parent, and the third form resembles the mother, either *scintillans* or *lata*. The phenomena of twin and triple hybrids is treated in detail by De Vries ('13) in "Gruppenweise Artbildung."

From a Mendelian standpoint the production of twin and triple hybrids is strong evidence that *Lamarckiana* and such of its "mutants" as behave in this manner are impure or hybrid since the male or female gametes are not uniform, a point which has been emphasized by several critics of the mutation theory. De Vries assumes that *Lamarckiana* forms its different classes of gametes as a result of its mutating instability but the precision of the process falls completley in line with what we know of Mendelian behavior. The remarkable studies of Shull show that crosses between *Lamarckiana* and *cruciata* give in the first generation polymorphic progenies of much greater complexity than the twin hybrids of De Vries. Shull's results have not been published in full but, as I understand them, they indicate the interaction of several classes of gametes, a condition very far from what would be expected if genetically pure species had been crossed.

Very interesting are the observations of Atkinson ('14) on first generation crosses between *Œnothera nutans* and *O. pycnocarpa*. These two forms are American species recently segregated by Atkinson and Bartlett from the *biennis* alliance. They have bred true in garden cultures. When *pycnocarpa* is pollinated by *nutans* twin hybrids appear in the first generation. In the reciprocal cross *nutans* × *pycnocarpa* the same twin forms are produced and in addition a third type, making this generation a compound of three distinct forms, triple hybrids. Atkinson, apparently confident of the genetic purity of *nutans* and *pycnocarpa* assumes that the determination of the twin and triple hybrids takes place through a differential division in the zygote by which factors representing certain characters are side tracked in the suspensor cell and only those responsible for the twins and triplets pass on to the embryo. There is no

cytological evidence that the first mitosis in the zygote of a higher plant is ever a differential division. To the writer the situation indicates that one or both of the two species is heterozygous and that for this reason classes of gametes are formed, appropriate combinations of which give the twins and triplets. No data has been published respecting the sterility of these two species, either of pollen or ovules, and nothing of seed abortion. An understanding of the genetic constitution of the species is likely to be a difficult matter, but it does not seem probable that both are pure.

What shall be said of the probable purity of the plants of *Œnothera* and *Raimannia* with which MacDougal worked in his experiments designed to create new species by the injection of certain fluids into the ovaries. The parent material was reported to breed true, but the cultures were small and not long continued and there is no reason to suppose that a complete germination of the seeds was obtained. No information is given on the fertility of the species either with respect to the abortion of gametes or the proportion of good seeds. The material was not tested by cross breeding with other forms (the purest known) to determine whether the F_1 hybrids were uniform, a most necessary test in the establishment of a stock as homozygous. Thus from our present viewpoint we cannot accept MacDougal's conclusion since the probabilities are very great that the new types which appeared in his cultures were produced not as the result of the injections but because of the genetic impurity of the plants themselves.

In the above discussion the writer has taken definitely a Mendelian attitude in sympathy with the criticisms of Bateson and the studies of Heribert-Nilsson ('12) and of Renner ('14). There are constant suggestions of order in the phenomena of inheritance among the œnotheras which while they may not fall into simple schemes of Mendelian notation nevertheless do indicate system even though masked by complexities. That the complications at least in great part are due to the genetic impurity of the *Œnothera* material which has been so far the subject of study is the writer's belief. The difficulties that surround the analysis of *Œnothera* inheritance are probably in very large measure due to the extraordinary amount of sterility, gametic or zygotic, or both, that is present in the group.

Upon students of this genus rests the responsibility of obtaining data on this sterility and, if possible, of discovering its causes. The assumption that a line represents a pure species because it breeds true is not a safe foundation upon which to conduct experimentation in the œnotheras. This is the assumption upon which have been based many of the conclusions of the Mutationists, and from it we must dissent. We cannot depart from the principles underlying Mendelian methods of research which have so brilliantly opened the present century of biological investigation.

Finally what are the tests that must be applied to an *Œnothera* species to determine whether or not it is pure.

First.—There is the breeding test and that must be applied with such experimental methods of seed germination (Davis, '15) as will insure a complete progeny from the sowing, a progeny wholly representative of all types of viable seeds. Even then the breeding test is negative rather than affirmative in its conclusions. Should the form throw off numerous variants it naturally becomes a subject of suspicion, but should it breed true or relatively true that does not in this group of plants prove it to be homozygous in its germinal constitution.

Second.—Information must be obtained on the character and degree of sterility present, both gametic and zygotic. Sterility, unless shown to be strictly physiological in its character, suggests genetic impurity.

Third.—Cross-breeding tests must be planned and followed in which the form under observation is mated with material of known genetic purity. If the hybrid plants of the first generation are essentially uniform and the result of a normal germination of the seeds the indications are strong that the form is truly pure provided that the gametes are likewise normally fertile. If the hybrids of the first generation fall sharply into classes the material must develop gametes of different germinal constitutions and is consequently heterozygous. One favorable cross with a pure species may not be sufficient to establish the purity of a form; a number of favorable tests with pure types will carry increasing conviction.

It is thus not an easy matter to determine the fact whether or not a species of *Œnothera* is pure, and yet this is fundamental to

experimental studies in the group. On the assumption of specific purity the Mutationists rest their conclusions. This condition with respect to the characters studied is also basic to Mendelian experimentation. It need scarcely be emphasized that no species of *Œnothera* has as yet passed the tests for genetic purity outlined above and that consequently we have at present no standard material with which forms may confidently be mated in the test of cross-breeding. It should become the concern of *Œnothera* geneticists to find and isolate pure material as the starting point of further studies in experimental morphology. Whether such pure forms will be found among the wild species or as products of the garden time will determine.

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CONCRETIONS IN STREAMS FORMED BY THE AGENCY OF BLUE GREEN ALGÆ AND RELATED PLANTS.

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(*Read May 7, 1915.*)

In 1898, I discovered that concretionary formations occurred in Little Conestoga Creek, Lancaster County, Pa. At that time, however, I was engaged in other studies and gave the concretions only a passing notice. But in the late summer of 1914, my attention was directed to the subject again by the reading of Dr. Walcott's paper on "Pre-Cambrian Algonkian Algal Formations" which appeared July 22, 1914. This paper made me realize the importance of a careful investigation of these particular stream formations as to characteristics, distribution, origin, etc. I began at once a careful and extended search in the Little Conestoga as well as in other streams for concretionary structures of recent formation. My search was amply rewarded by finding them in great quantities, and distributed throughout nearly the entire length of the Little Conestoga. I found also that they not only occur in the creek itself, but that quite large deposits of the concretions underlie the flood plain meadows along the creek banks. One of these in Kendig's Woods, two miles southwest of Millersville, Pa., is made up wholly of concretionary materials on the top of which forest trees of large size and considerable age are growing. This deposit covers nearly an acre to the depth of about 8 feet in the middle thinning out lenslike toward its edges. Another deposit along the same stream near Fruitville in Evan's Meadow, more extensive in area but of slighter depth, forms a substratum under a thick soil cover and has an average depth of about two feet. Deposited concretions occur under similar conditions in many other of the meadows along the stream as is shown by weathered concretions occurring in the soil and wash wherever wet-weather stream gullies have been torn through the soil cover.

Though these structures, as I shall show later on, are without doubt due to Algoid agency in the stream waters, it may be well to premise the full discussion of their origin by somewhat complete descriptions of their characteristics as to form, size, structure, etc. In this way the attention of botanists and geologists will be directed to their study and distribution, so that their significance as agents of rock formation and the flora, responsible for their growth, may be fully worked out.

Size and Shape.—The concretions both in the stream and in the deposits vary in size from peas to masses nearly a foot in diameter (see Fig. 1). The latter size is not very common in the

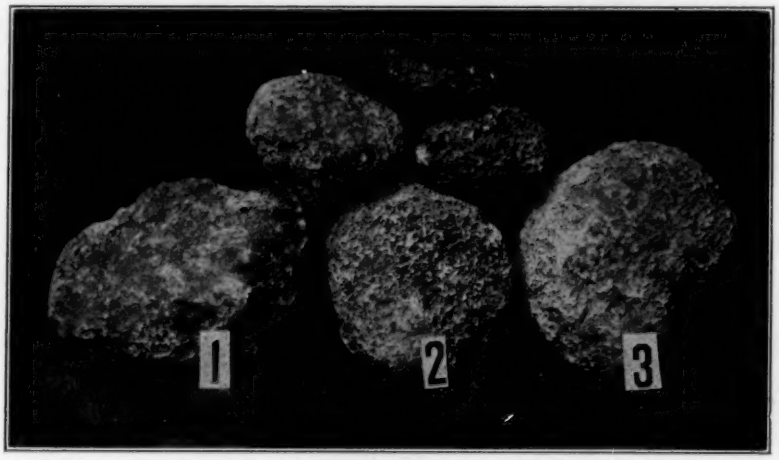

FIG. 1. A group of the concretions showing their size, shape, surface appearance and color. No. 1 is 7½x10 inches; No. 2 is about 5 inches in face diameter and 3 inches thick; No. 3 is 8x7x5 inches. The two smaller concretions above are typical, both in color and surface appearance, of growing specimens.

stream but many large concretions occur in the deposits probably because the smaller ones after deposition in land forms have been carried away in solution by percolating waters leaving only the larger forms. In the flood deposits in Kendig's Woods thousands of the concretions when I found the deposit last summer measured nearly a foot in length and six inches or more in transverse diameter.

The smaller concretions are invariably ellipsoidal in shape (see Fig. 1), and quite symmetrical unless broken by flood action. The larger sized concretions, though of the same general shape, are less symmetrical. Those in the stream are nearly always more regularly ellipsoidal than those of the deposits in flood plains and stream bars. This is, no doubt, due to their weathering through solution or to their having been broken by flood waters during their transportation to their present positions.

The concretions in the stream are quite firm in texture; those in the deposits are less compact. Both are porous and roughly coralline in general appearance and internal structure.

In color they vary from bluish green to whitish. The growing specimens in the stream are generally bluish green. All specimens after exposure for some time to sun, air, and rain or to the action of soil waters become grayish white.

Composition and Hardness.—Though the composition varies slightly from place to place yet all are limy deposits concentric around a nucleus. The main constituents in the concentric layers are calcium carbonate, silica and organic matter of vegetable origin. Upon dissolving out the limy constituents with dilute hydrochloric acid, a mat is often left of vegetable materials composed of the matted stems or tissues and cells of low type plants such as mosses and algæ.

Few of the specimens tested had a hardness as great as that of common calcite, most of them being about two in the scale of hardness. The weathered concretions are generally less coherent than those now forming in the stream.

The following table shows the main constituents of the concretions:

Constituents.	*A.*	*B.*
Organic matter	10% to 15%	1 to 12%
H_2O	1%	1%
SiO_2	12%	12%
$CaCO_3$	60% to 75%	70 to 80%
Fe	1%	2%
Al	Trace	Trace
$MgCO_3$	Trace to 1%	Trace to 1%

A of growing specimens.
B of specimens from flood plain deposit.

Structure.—Most specimens have as the nucleus a quartz or limestone pebble of the country rock. Near Millersville, where the stream flows for a mile or two parallel to an igneous dyke, the nuclei are diabase pebbles. But some specimens lack the stony nucleus having instead the limy layers concentric around a dark spot which proves upon close examination to be carbonaceous matter resembling nearly structureless peat. Probably this was originally a piece of wood or other vegetable tissue that carbonized after the concretionary laminæ had accumulated around it. This supposition has been verified in a number of cases by finding concretions with organic matter as nuclei (see Fig. 2).

FIG. 2. Sections of a group of the concretions showing the laminae, concentric arrangement of the laminæ, the nucleus or nuclear point, and eccentric manner of growth. One-third natural size. The nucleus in the small upper specimen is a small water worn quartz pebble. The larger upper specimen shows where the nucleus was broken out when the section was made.

The concretions with stony nuclei may always be detected by their higher specific gravity.

Around the nucleus of a specimen is layer on layer of the limy matter each lamina from one eighth to one fourth of an inch in

thickness. The laminæ are not equally compact throughout their thickness, but are open and porous within and quite solid without. A polished section of any concretion exhibits many concentric ellipsoidal layers with the nucleus nearly always eccentric and the successive layers with a greater thickness on the one side and two ends than on the other side. The thickness of the successive laminæ in any one direction out from the nucleus is nearly uniform. In other words, along any radius the inner layers are just as thick as the outer ones. When found in place in the stream where the concretions have not been disturbed for a long time, the down side laminæ are invariably a little thicker than those on the upper side. This indicates that the greater growth is downward.

In appearance and structure, the concretions of the Little Conestoga are very similar to the "Lake Balls" from Lake Canandaigua, New York, so vividly described by Dr. Clarke, under the name of "Water Biscuits." They are also somewhat similar though much larger in size to the oölitic sands found forming in great numbers in the waters of Great Salt Lake by A. Rothpletz and traced by him to the agency of blue green algæ.

Where Found.—Upon recognizing the importance of a thorough study of the Algoid concretions, I began a systematic search in all parts of the Little Conestoga as well as in other streams of both Lancaster and York Counties, Pennsylvania. My search showed that these objects abound in all parts of the Little Conestoga nearly from source to mouth. But no other streams in this part of the state have so far yielded any specimens. Those found in the sand bar in Lake Canandaigua near the mouth of Sucker Brook are probably also of stream origin, and I feel confident that a careful search in the brook would reveal at least some, if not many, of the concretions. Substances somewhat similar in composition occur in other lakes than Canandaigua though they do not have the concretionary form. Thus laminated reef-like accumulations of Algoid origin occur in Round Lake, New York, while marly or tufaceous deposits have accumulated for ages and are still forming in many lakes in Michigan, Wisconsin and Indiana. The tufa and thinolite described by Russell as forming in Pyramid Lake, Nevada,

are now regarded as of similar origin though differing much from the Little Conestoga concretions in both form and structure.

That concretions similar to those found in the Little Conestoga occur in other streams is evident from observations made in Center County, Pennsylvania, by Dr. Wieland, who, however, had not recognized them as of Algoid origin until I called his attention to the well known activity of some algæ in precipitating calcium carbonate. In a recent personal letter to me Dr. Wieland describes concretions that he found in 1888 in a stream near Lemont, Center County, Pa. He, however, says, "I just thought of them as very interesting objects from the viewpoint that they showed once more how abundant is CO_2 whether derived from plants or other sources. In short I knew too much and too little to make the least use of what I found."

Origin.—In 1854, W. Ketchell in the First Annual Report of the Geological Survey of New Jersey refers to *Chara* as active agents in the formation of fresh water marl. In 1864 Frederick Cohn found that a number of aquatic plants, especially *Chara* Mosses and Algæ, caused the deposition of travertine at the waterfalls of Tivoli. The deposition he attributed to the activity of the plants in absorbing carbon dioxide and so setting the lime carbonate free. That is, these low type plants consume carbon dioxide and exhale oxygen. When this is done in water containing calcium bicarbonate they deprive that salt of its second molecule of carbonic acid and the insoluble neutral carbonate of lime is precipitated.

W. S. Blatchley and G. H. Ashley in their report on the lakes of Indiana in 1900 also refer to the activity of plants in the precipitation of insoluble lime carbonate. But they also thought that the dissolved lime brought into the lakes by streams and deposited mechanically by evaporation was a more important agency than the plants.

In 1900 C. A. Davis discussed the origin of the marls of the lakes of Michigan and came essentially to the same conclusion as Cohn. He says:

"But in water containing amounts of salts, especially of the calcium bicarbonate, so small that they would not be precipitated if there were no free carbon dioxide present in the water at all, the precipitation may be consid-

ered a purely chemical problem, a solution of which may be looked for in the action upon the bicarbonates of the oxygen set free by the plants. Of these calcium bicarbonate is the most abundant, and the reaction upon it may be taken as typical and expressed by the folllowing chemical equation, $CaH_2(CO_3)_2 + O \rightarrow H_2O + CaCO_3 + CO_2 + O$, in which the calcium bicarbonate is converted into the normal carbonate by the oxygen liberated by the plants and both carbon dioxide and oxygen set free, the free oxygen possibly acting still further to precipitate more calcium monocarbonate, $CaCO_3$."

Dr. F. W. Clarke in "Data of Geochemistry" says:

"That Dr. Davis' theoretical equation (given above) rests on no experimental basis."

In an article in *Science* dated December 14, 1914, J. Claude Jones, of the University of Nevada, says that the tufas of Salton Sea and of Pyramid Lake owe their origin to blue green algæ. He shows that wherever these plants are present in Pyramid Lake the gravels are cemented together and wherever the algæ are absent no trace of the tufas can be found.

Dr. Clarke ascribes the origin of the "Water Biscuits" of Lake Canandaigua to the same agency.

Miss Josephine Tilden in *Minnesota Algæ* (1910) says that *Gleocapsa calcarea* forms a calcareous crust (with other lime secreting forms) on boards where spring water from a trough drips down constantly.

Weed in his classic report (1889, U. S. G. S.) on the rock formations of the hot springs of the Yellowstone National Park shows that travertine as well as siliceous sinter are deposited through the aid of algæ.

Dr. B. M. Davis, of the University of Pennsylvania in a very interesting paper (*Science,* Vol. VI., July 30, 1897) describes the algæ and bacteria active in the formation of the travertine and siliceous sinter deposits in Yellowstone Park.

Dr. MacFarlane, of the University of Pennsylvania, in speaking of the activities of thermophilic algæ of hot spring and geyser regions, ascribes many rock formations throughout the earth's history as due to the work of fresh water algæ especially of the group Cyanophyceæ.

Evidences That the Active Agents of the Concretionary Formations in the Little Conestoga are Blue Green Algæ.

That the concretions described in the first part of this paper are the result of life processes of plants may be proved in a number of different ways. (1) The color of all growing specimens in the stream is the characteristic bluish green color of the Cyanophyceæ, while those exposed to rain and sunshine are grayish white. Careful microscopic examination also of such growing specimens reveals a varied thallophytic flora mainly of the Cyanophyceæ. Species of the genera *Gleocapsa, Gleotheca, Aphanocapsa, Nostoc, Oscillatoria* and *Rivularia* have been identified. Associated with these are several of the green algæ (Chlorophyceæ). Many species of the Diatomaceæ and Desmidaceæ which generally live in close association with blue green algæ have also been identified and have, no doubt, contributed the siliceous matter which is disseminated through the calcareous matrix. Among the diatoms, species of the genus *Navicula* both in free forms as well as stalked forms on algæ are quite prominent. The *Charas* are also occasionally present, contributing a small percentage of so-called marly material. Some bacteria have also been found in association with the other plants but the bacteria have probably had little to do with the calcareous deposition, but may contribute the iron which I find present in every concretion that I have analyzed.

(2) The arrangement and structure of the laminæ also favors the view that these concretionary accumulation are due to life processes. That periodic accretion alternates with a period of quiescence is shown plainly by the concentric laminations of nearly uniform thickness. The open porous nature of each lamina within and the more solid character without, like the concentric arrangement, is due without doubt to the seasonal conditions of the region. Since algæ are essentially thermophilic plants, each winter destroys many of them and stops the growth of most of the rest and thus at the beginning of the plant year (spring) few and widely scattered algæ at first produce slow and scattered accretion of the limy matter; later the plants become more abundant and by summer they are crowded over the surface of each mass. This distribution of the algæ seasonally would naturally have its effects upon the struc-

ture and arrangement of the limy matter giving a decided though rough coralline appearance to the inside portion and a more compact texture to the outer part. The theory just given has been confirmed by a study of the distribution of the algæ on the concretionary bodies through the seasons. The fact also that when the limy matter is dissolved out with acids, a mat of vegetable chains and cells remains nearly as large as the original concretion is also confirmatory. Even in the concretions which are centuries old as those in the forest covered deposit in Kendig's Woods the dead cells and chains of blue green algæ may be found.

(3) Lime secreting algæ are found in the Little Conestoga during the entire year but abound from May till December. They occur not only in the water but encrust many objects, in a few places forming small reef-like accumulations similar to those in Round Lake, New York.

(4) Quite an array of investigators, among whom we may mention Agassiz, Bigelow, Gardiner, Murray, Finckle, Vaughan, Walther, Drew, Matson, Dall, and Sanford, have studied at first hand the activities of algæ of the genera *Lithothamnion* and *Halimeda* and also some of the bacteria in various parts of the ocean and in many seas. All have come to the conclusion that many of the so-called coral reefs owe their existence partly and often largely to the activities of these lowly plants. The Bermudas, the Bahamas, the Laccadive and Maldive Archipelagoes, Funafuti, and extensive rock beds in the Floridian Peninsula have all originated through plant agency as much as through coral polyps. If this be true, it is not only possible but probable that fresh water blue green algæ throughout all the ages have caused and are still causing the precipitation of rock materials from minerals in solution in streams and fresh water lakes.

(5) Weed has proved that the concretions formed in geyser basins and known as Geyserites are formed by algæ which through life processes cause the precipitation of the siliceous matter held in solution in the hot water.

(6) The observation that the laminar accretion seems to proceed more rapidly on the under side of a concretion proves that the formations are not due to mechanical precipitation of lime carbonate

through evaporation or change of temperature. It does, however, suggest that the secretion or precipitation is chemical and dependent on a life process that produces conditions for chemical reaction where the plants or animals are most abundant.

(7) Conway MacMillan in *Minnesota Plant Life* says:

> "Some slime moulds have the power of incrusting their tiny fruit bodies with lime which they extract from their soil or from rain water which falls upon them. Such forms are often observed in Minnesota upon dead wood or fallen leaves, generally, in moist shady places in the deep forest. Some of the blue green algæ have the power of encrusting themselves with lime and in watering troughs and tanks there sometimes occurs a calcareous formation reminding one of the deposit in old tea-kettles. Such a crust is true limestone extracted from the water by the chemical activities of the algæ."

Upon a larger scale the blue green algæ have been conclusively shown by Weed to be important factors in travertine formation in the hot springs and geysers of Yellowstone National Park.

Dr. MacFarlane without knowing of my discovery in the Little Conestoga Creek has expressed the opinion that these apparently insignificant plants have throughout all the ages played and are still playing in all waters an important part in the formation of limestones and dolomites.

(8) The fact that many more or less ancient rocks have been demonstrated to be of algoid origin by various scientists and are similar to the Little Conestoga concretions in their concretionary or laminated structures or both is favorable to the view that algæ are just as important agencies in rock formations in the present geological epoch as in the past. The similarity of *Cryptozoön proliferum,* Ozarkian oölitic formations, *Newlandia frondosa, Camasia spongiosa, Collenia compacta, Collenia undosa* and other structural forms in rock formations to the work of recent algæ in hot spring and geyser regions has been vividly shown by Walcott, Wieland, B. M. Davis and others. Some, at least, of the above-named formations can be strikingly duplicated in their structural peculiarities by the Little Conestoga concretions and reef-like masses of Round Lake,—the Potsdam-Hoyt formation of New York state being especially like what would result were infiltrating waters, cementation, and other solidifying agents or processes to act for a long time upon the great mass of flood deposited concretions of the Little Conestoga in Kendig's Woods.

Mineral Content of the Little Conestoga Waters.

One would infer from the number of concretions growing in the Little Conestoga and also from the thickness of each lamina in a concretion that the mineral content of this stream's waters is high. I have verified this by determining the salinity of the stream under varying conditions. The salinity in a wet month was 330 parts in a million, while in a dry month this rose to 365 parts in a million. Streams in which I have found no trace of concretionary structures have a much lower salinity, the Big Conestoga Creek for example having a salinity of 190, the Pequea Creek 195, and the Susquehanna, in March, above the mouth of the Pequea and below the mouth of the Big Conestoga, about 200 parts in a million. The various springs flowing into the Little Conestoga have an average salinity nearly as high as that of the Little Conestoga itself.

The basin of the Little Conestoga is underlain with much more soluble limestone than any of the other streams so far investigated. This accounts for the high salinity of its waters and also for the distribution of the concretions so far as we know that distribution. Further search and study will certainly reveal that many streams of the world contain concretionary structures and determine the conditions of their distribution and formation. I trust the beginning I have made in the investigation of stream concretions will lead to a wide and thorough study of this interesting and important biological as well as geological problem.

The various facts tabulated on page 257 and correlated with the fact that the blue green algæ are about equally abundant in the various streams mentioned in the table would seem to indicate that deposition of $CaH_2(CO_3)_2$ is always going on in all the streams during the growing season, but that when the salinity is low solution by the stream waters balances deposition and no concretions are formed. When, however, the salinity is high, solution can not take place and laminated structures due to seasonal or other changes are formed either in concretionary form or more rarely as reefs. This is put forward as a working hypothesis, many more observations and analyses are needed however before the various problems connected with these formations can be fully solved.

TABLE SHOWING RELATION BETWEEN THE SALINITY OF STREAMS AND THE PRESENCE OF CALCIUM CARBONATE CONCRETIONS.

Stream or Spring.	Month.	Salinity, Parts in One Million.	Nature of Salinity (Chiefly).	Concretions Present in Stream.
1. Little Conestoga.....	Feb. 5	330	$CaH_2(CO_3)_2$	Abundant
2. Little Conestoga.....	March	300	"	"
3. Little Conestoga.....	April	365	"	"
4. Branch Run, tributary to Little Conestoga.....	April	91	"	None
5. Big Conestoga.....	Feb.	152	"	None
6. Big Conestoga.....	March	100	"	None
7. Big Conestoga.....	April	150	"	None but many gasteropods
8. Duing's Run, tributary to Big Conestoga.....	April	195	"	None
9. Pequea Creek.....	April	195	"	None
10. Donegal Run.....	April	404	"	Abundant
11. Nissley's Dam in Donegal Run, further upstream than 10.....	April	400	"	Many but small
12. Donegal Run near source...	April	230	"	None
13. Bellaire Branch of Donegal Run.....	April	208	"	None except near mouth
14. Little Chickies.....	April	170	"	None
15. Big Chickies.....	April	171	"	None
16. Big Chickies farther upstream.....	April	174	"	None

FURTHER NOTES ON CONCRETIONARY FORMATIONS IN STREAMS.

Since writing the above I have been fortunate enough to find a new locality for concretions. Knowing that Donegal Township, Lancaster County, comprised a notably large area of Cambro-Ordovician limestones, I judged that its streams would be favorable to the growth of calcareous concretions through the agency of blue green algæ. Search on April 25, in Donegal Creek, revealed these objects in greater abundance than in the Little Conestoga. One meadow of fully 12 acres bordering the stream about one mile northeast of Marietta was found to be underlain with a bed of concretions not less than a foot in average thickness throughout its entire extent. And this was under a soil cover of more than a foot in depth that had, apparently, resulted from the weathering and disintegration of the same objects. The great flood deposits of concretions in this and neighboring meadows were paralleled by large quantities in the stream itself, fully one fifth of the stones in some

places in the stream channel being of concretionary origin as shown by their shape, laminated structure, and composition.

The finding of the new locality is of great interest. It shows that a careful, intelligent, and systematic search will reveal these formations in many other regions of the world wherever the proper conditions exist for calcareous and siliceous precipitation through the life processes of plants.

But the geological significance of the great meadow deposits also needs emphasis. The large accumulation in the Donegal Township Meadow represents a comparatively long period and this indicates a considerable antiquity of the plants which form the concretions. Then too, such a bed of closely packed concretions is highly suggestive of the manner in which some ancient rock beds originated. For were such accumulations of concretions as those in the Donegal Meadows to be consolidated by the action of infiltrating waters, pressure, heat and chemical change solid rock beds would result nodular in appearance and concretionary in structure hardly distinguishable from the Hoyt Potsdam beds of New York.

Species of the following genera of the Cyanophyceæ are found associated with the calcareous concretions occurring in Donegal Creek, Lancaster County, Pa..: *Glœocapsa, Microcystis, Cœlosphærium, Aphanocapsa, Oscillatoria, Rivularia, Nostoc, Chroococcus.* There are also species of *Protococcus,* many species of Diatoms, several species of Desmids, various species of the Chlorophyceæ, several species of Phæophyceæ, and species of Rhodophyceæ.

THE CONDITIONS OF BLACK SHALE DEPOSITION AS ILLUSTRATED BY THE KUPFERSCHIEFER AND LIAS OF GERMANY.

By CHARLES SCHUCHERT.

(*Read May 7, 1915.*)

Stratigraphers do not agree as to the conditions under which the black bituminous shales so often met with in American Paleozoic marine deposits were laid down. Among the more striking of such formations may be mentioned the Quebec, Martinsburg, Collingwood, Utica, Maquoketa, Genesee-Portage, Ohio, Chattanooga, and Caney, formations ranging from the Ordovician to the Pennsylvanian. To aid in the interpretation of such black shales, the writer presents herewith the main results set forth by Professor J. F. Pompeckj, of the University of Tübingen, in a publication that will not be of wide distribution in America.[1] The following is a decided condensation and in part a free translation of his exhaustive paper, which is replete with bibliographic references.

The Kupferschiefer of Germany are of Middle Permian age, and occur near the base of the Zechstein, the time of marine invasion over the previous continental series known as the Rotliegende. In general, the bituminous dark shales occur above the basal Zechstein conglomerate and below the Zechstein dolomite, and occupy an area of at least 60,000 square kilometers in middle and western North Germany. The average thickness of the copper shales over wide areas is about 30 inches, but varies from nothing to a maximum and exceptional local thickness of 35 feet. However, in many places there are no black shales and then the equivalent deposits, or the basal strata of the invading Zechstein, may be conglomerates, sands, shaly limestones, or dolomites. In other words, the black bituminous shales do not prevail everywhere, and the same is true of the metal sulphides.

[1] "Das Meer des Kupferschiefers," Branca-Festschrift, 1914, pp. 444–494.

The copper-bearing shales usually succeed the basal conglomerates or sands and finally become gradually more and more calcareous, passing upward into the normal Zechstein dolomite of wider distribution. The latter has an abundant though monotonous fauna indicative of peculiar marine conditions and not much like that of the Tethyian mediterranean to the south, which is of normal sea environment. The paleogeography indicates an inland sea, bounded by continuous land, in the north by Fennoskandia across to England, thence south to France and Belgium, and east over South Germany to Bohemia. In the east only were there limited connections with the Russian and Arctic Zechstein sea. The previous orogenic movements resulting in the Paleozoic Alps of central Europe had been greatly reduced, so that the streams flowing into this Permian sea were sluggish and delivered only the finest of muds and solution materials, while those flowing out of regions of igneous rocks were charged in addition with copper, zinc, and silver.

The Kupferschiefer are fissile, tough, dark to black, highly bituminous (6 to 20 per cent.), clay shales with considerable calcareous material that increases in amount upward (locally to 45 per cent.). Copper sulphides variable in quantity and nature are present, and because of this ore the strata have been mined in Germany for seven hundred years. Under the microscope the shale is seen to be made up of finest clay substance colored yellow-brown to black by bitumen. Throughout the clay there are scattered, layered, or aggregated in the form of thinnest lenses varying amounts of tiny crystals of calcite and needle-like splinters of quartz. Black coaly dust is also more or less abundant and especially among the clay particles.

The flora and fauna of the Kupferschiefer are small and at best do not include more than 1 land stegocephalian, 2 land reptiles, 17 fishes (5 selachians, 1 crossopterygian, the rest ganoids) with structures indicating forms that lived on or near the bottom of the waters, 1 nautilid, 1 gastropod, 1 scaphopod, 10 bivalves, 3 bryozoa (Fenestellidæ), 5 brachiopods, 1 problematic starfish, and 11 species of land plants. This assemblage is brought together from many localities and the species of fishes are usually based on single specimens, indicating that the biota is not a natural assemblage, but is

made up of land and marine forms plus fishes, most of which appear to be of fresh water habitat. The only common fossils are the ganoid *Palæoniscus freieslebeni, Lingula credneri, "Asterias" bituminosa* (problematic), and the small bivalves *Nucula beyrichi* and *Bakewellia antiqua* (sometimes in colonies). In other words, the life consists of land-derived forms (3 vertebrates and 11 plants), fishes (5 probably marine and certainly bottom-feeding, and 12 apparently of river origin), and 22 marine invertebrates all but one of which are forms living on the bottom of the sea, attached to it or to floating objects. While the invertebrates indicate plainly that the copper shales were laid down in the sea, the great scarcity of fossils shows that the forms recovered are in the main not in their normal habitat. It appears that only 3 species (the invertebrates cited) were able to adapt themselves to the peculiar conditions of the copper-depositing seas. Not a single scavenging animal is found, and the fact that so many fishes (17 species) were present as food (*Palæoniscus freieslebeni* is often more or less decomposed by sulphur bacteria) indicates that the bottom had no scavengers and that it was not a favorable place for any kind of life.

Pompeckj has carefully studied the fishes, and as all or most of them are carnivorous (some are shell-feeders) the question is raised: On what could they have fed, since there was so little bottom life? He admits that there may have been present an abundance of soft-bodied and shell-less invertebrates on which they preyed, but finally concludes that it is much more correct to assume that most of the fishes (at least 12 species) were drifted into the sea from the rivers. If they also lived in the sea, it must have been in the oxygenated surface waters or the shallow shore regions. On the other hand, the invertebrates present indicate that nearly all of them fed on microscopic plants and animals (no ostracods are present, however) and it is perfectly natural to assume that the surface and sun-lit waters abounded in a varied plankton, as do the seas and oceans of today. It was this world of minute forms, the plankton, that rained into the depths, feeding the sparse brachiopod and molluscan life and the common sulphur bacteria.

Moreover, it is the abundant surface plankton that in all probability has furnished most of the bituminous matter, assisted further

by the land-derived fishes, while the coaly substance has resulted from the land plants. Along the shores, in the oxygenated waters, there probably also was an abundance of sea-weeds and among them doubtless lived most of the invertebrates preserved in the Kupferschiefer. The marine plants are broken up by the storms, and the water currents plus the undertow generated by the waves and tides drag this material into deeper waters, where it is slowly rotted and further altered by the sulphur bacteria. There results a foul bottom, free of oxygen, and reeking with carbonic acid and sulphuretted hydrogen gas. The chemical reactions set up here (diagenesis) result in the deposition of the metal sulphides (copper, zinc, silver) and the bituminous alteration products.

The paleogeography, as stated above, indicates an inland and almost land-locked sea. Into such a basin the currents generated in the oceanic areas can at best enter but little, and that such did not enter in any marked degree is seen in the almost complete absence of floating and swimming invertebrates. As for the general physical conditions, Walther thinks of stagnant waters, with marine swamps; Kayser of quiet bays of inland seas with foul bottoms; and Dosz of stagnant places like the present bays around the island of Oesel, where the bottoms are rich in iron sulphide deposits, the healing or medicinal muds. Pompeckj, however, finds more or less valid objections to all of these suggestions, and thinks the best present analogue to be the Black Sea, whose physical and organic conditions are now well understood through the work of Andrussow and Lebedintzew. In other words, the Kupferschiefer sea is "a fossil Black Sea" in nearly all its characteristics except depth.

With regard to the conditions of the Black Sea, it is an inland, relic sea, which was once a part of the Tethyian mediterranean. Its greatest length is about 715 miles and its maximum width 380 miles (making its area 170,000 square miles), and it attains 7,360 feet in depth. Flowing into it are many rivers, among the largest of which are the Danube, the Dnieper, and the Don. Its only outlet of surface water is through the strait and over the barrier of the Bosporus into the Sea of Marmora and thence through the strait of Dardanelles into the Ægean Sea and the Mediterranean. A compensating but smaller inflow of salt water (salinity 3 per cent.)

occurs at greater depths. The shores are high and bold on the northeast, east, and southwest, and flat on the north and northwest.

Andrussow[2] has described the physical and bionomic conditions of the Black Sea as follows: Beyond the shallow marginal waters of 600 feet depth there is no bottom-living life (benthos), while in the surficial fresher waters down to about 750 feet there is a more or less great abundance of floating, usually microscopic, open-sea forms (plankton) and the larger, free-swimming life (nekton), collectively also spoken of as the pelagic biota. This upper layer of freshened water and its peculiar life conditions are brought about by the enclosed nature of the deep basin, the inflowing of immense quantities of less dense fresh water that remains at the surface or is there evaporated, and a deep-seated, partially compensating current of salt water from the Sea of Marmora through the strait of Bosporus. It is estimated that it takes about 1,700 years to renew the entire salt-water content of the Black Sea.

Because of these differences between the lighter surface and the heavier bottom salt waters, there is no vertical streaming nor convection currents beyond 750 feet of depth, and therefore no replenishing of the deeper marine waters with the oxygen that is so necessary for the maintenance of benthonic life. At the depth of 600 feet, hydrogen sulphide begins to form (33 c.c. in 100 liters of water) and increases rapidly with the depth to 3,000 feet (570 c.c.) and then more slowly to the bottom of the sea. The formation of the H_2S is in the main due to the sulphur bacteria. Hand in hand with the increase of the H_2S goes the decrease of the sulphates in the sea water and the precipitation of the carbonates and iron sulphides.

That the aëration of marine waters, and also the generation of sulphuretted hydrogen may be better understood, a digression into the studies of oceanographers becomes necessary. The atmospheric gases, oxygen and nitrogen, are absorbed at the sea surface more abundantly in cold than in warm latitudes, and the quantity absorbed is again variable under varying pressures and chemical conditions of the water. This complex subject, too long to state here, may be

[2] "La Mer Noire," Guides des Excursions, VII[e] Cong. Géol. Internat., St. Pétersbourg, 1897, Art. XXIX.

studied in Krümmel's "Handbuch der Ozeanographie," I., 1907, pages 292–317. Furthermore, the amount of oxygen is increased when there is an abundance of assimilating plants, as in the areas of the sea-weeds and diatoms. The gases are then distributed by the general water circulation to most parts of the oceans and even into the greatest depths. In general, there is an abundance of oxygen down to 350 feet, but in the tropics it is wanting in the greater depths of the shelf seas. The oxygen is consumed by the animals and by various hydro-chemical processes and consequently diminishes in quantity as it is carried down from the surface and over the bottom, but the quantity of nitrogen remains constant. Sir John Murray states further that in the streaming open ocean of today there is usually an abundance of oxygen even at the greatest depth, due to the sinking heavier and colder polar waters, but this is not the case in partially enclosed seas which are more or less cut off by barriers and where the water is said to be "stale," and in the deeper layers of which vertical circulation is restricted.

Similar stagnant conditions "prevail in several Norwegian 'threshold fjords,' or on a smaller scale in the oyster-'polls.' In such places the bottom is thickly covered with organic matter; a slimy black mud is formed, swarming with bacteria that produce sulphuretted hydrogen, which spreads through the water, combining with the oxygen to form various sulphates. This causes the oxygen to decrease and finally to disappear altogether, when the sulphuretted hydrogen begins to appear free in solution. It gradually spreads upwards, until the water is devoid of oxygen and contains free sulphuretted hydrogen, at a depth of only 100 fathoms in the Black Sea, and in the oyster-basins in autumn often at merely a couple of meters below the surface. In summer the 'bottom-water' of the oyster-'polls' lies stagnant, but in the course of the autumn and winter it is generally renewed by the supply of comparatively heavy water from without; then the sulphuretted hydrogen disappears and the oxygen returns, producing thus an annual change in the gaseous conditions of the deeper parts of the oyster-'polls.' In autumn the state of things may become critical for the oysters, which are suspended in baskets at a depth of 1½–2 meters; it hap-

pens occasionally that the animals all die at this time by suffocation through want of oxygen or by sulphur poisoning."[3]

Johnstone[4] states that "In some parts of the sea, as for instance in the 'dead grounds' of the [very shallow] Bay of Kiel, in some parts of the Black Sea, and perhaps in parts of some of the Norwegian fjords, where the water circulation is defective, and where there may be a deficiency of oxygen, very remarkable bacteria are to be found. These are the sulphur bacteria, the occurrence of which is not, however, confined to these habitats. In the places I have mentioned sulphuretted hydrogen is evolved from the decomposition of dead organic matter, and this sulphuretted hydrogen, to us a vilely smelling and poisonous gas, is utilized as food substance by the bacteria. Such a microbe as Beggiatoa takes in the SH_2 and oxidizes it so that the sulphur is deposited in the cells of the bacterial colony, and the hydrogen appears as water. This is the form of assimilation of the organisms. Then some of the sulphur thus resulting from the decomposition of the SH_2 is oxidized to sulphuric acid. This is the form of respiration of the organism. It requires some source of nitrogen for the formation of its living proteid and this it obtains from the minute quantities of nitrates and nitrites which exist in solution in the water in which it lives. But it requires very little nitrogen compound, for whereas a higher animal may require to oxidize some of the living nitrogenous tissue of its own body in order to obtain its energy, the sulphur bacterium oxidizes the sulphur stored in its cells as the result of the assimilation of the SH_2. Thus the proteid part of the cell is protected from waste, and the minimal quantity of nitrogenous food-stuff suffices."

Krümmel states that the troughs of the Baltic Sea renew their deeper water irregularly and periodically. In the Rügen and Bornholm troughs (about 325 feet deep) the renewal takes place at least once and more rarely twice each year, in the Danzig trough (about 325 feet deep) nearly every year, and in the deeps off Gotland and in the Gulf of Bothnia usually only after many years. All these troughs get the new deeper water from the western Belt Sea and more rarely also from the Öresund east of Denmark.

[3] Sir John Murray, "The Depths of the Ocean," 1912, pp. 257–258.
[4] "Conditions of Life in the Sea," 1909, p. 264.

To return to the Black Sea and its sediments, these are of three categories: (1) from the shore to about 120 feet occur the accumulations of sandy detritals; (2) from 120 to 600 feet is found a gray-blue sticky ooze, often replete with small fragile shells, mainly of Modiola; and (3) in the greater depths the bottom is covered with (*a*) a tough, sticky, black ooze, with much precipitation of iron sulphide, an abundance of diatoms and fragments of the youngest stages of bivalves, all of which organisms are from the plankton, and (*b*) the dark blue ooze poor in iron sulphide and richer in the finest-grained $CaCO_3$, which in places forms thin banks, and an abundance of pelagic diatoms. Zones 1 and 2 alone have benthonic organisms, with the greatest abundance between 210 and 600 feet; the latter is the zone of *Modiola phaseolina* and a great variety of bivalves and gastropods (68 species occur in the shallower waters).

The Kupferschiefer sea, like the Black Sea, had bottom waters with about the average normal salt content, as proved by the typical Zechstein invertebrates. However, because of the lack of oxygen and the high content of sulphuretted hydrogen and CO_2 an abundant bottom life was impossible. That the top water of the Kupferschiefer sea was also fresh is proved by the wide distribution of the freshwater fishes in the sediments, the widely uniform spreading of the thin zone of shale, and the presence of land plants and land vertebrates. If all the water had been salty, the fine muds should have been laid down in a narrow zone bordering the margin of the sea, and this is not the case in the Kupferschiefer sea. The slow decomposition of the organic remains (mainly the plankton) and the lack of oxygen in the depths led further to the formation of the bituminous content (from 6 to 20 per cent.).

As the Black Sea goes down to 7,360 feet, the question must be asked: What was the depth of the Kupferschiefer sea? A positive and exact answer can not be given, but the small thickness of the shale over wide areas, combined with its intimate and variously modified connection below with the Zechstein conglomerate and above with the Zechstein dolomite, and its shallow-water life, show that "it is a deposit of the shallowest and shallower seas." To the reviewer, the depth seems to be well within that assigned the

continental shelf seas, *i. e.*, less than 600 feet. The freshwater covering Pompeckj thinks was thin.

Just as in the Black Sea the marginal fresh waters are depositing sands and other littoral sediments that are free of bitumen, so in the Kupferschiefer sea there is some evidence of marginal sands, sandy and clayey limestones, and regions free of metal sulphides.

Later, the black sea of Permian time gradually changed, first locally and finally everywhere, into the limestone-dolomite or Zechstein sea, still, however, an inland sea but devoid of muds and bituminous materials. In the shallow regions nearer the shores arose reefs of bryozoa, but at best the Zechstein sea, even when in widest connection with the ocean, had a small and monotonous fauna.

In an earlier paper Pompeckj[5] discusses a similar deposit, the zone of *Posidonomya bronni* of the Upper Lias of Germany. It seems desirable to cite also some of the details given in this paper, because they are somewhat different from those concerning the Permian. The deposits are fissile, calcareous, bituminous, dark shales rich in iron pyrite. Locally there are also horizons of sandstone, barren of life, and layers of stinking limestone. These deposits are found in northwestern Germany (about 40 feet thick) and France.

In Germany (Swabia and Franconia) the fossils consist of diatoms and coccoliths, horn sponges, very rarely a sea-urchin, crinids (sometimes with stalks over 50 feet long), a few forms of brachiopods, about 18 species of bivalves (of which the only common one is *Posidonomya bronni,* but this very thin-shelled form is at times exceedingly abundant; also *Pseudomonotis substriata, Inoceramus dubius, Pecten contrarius*), and rarely a gastropod or crustacean (Eryon). Besides the common bivalves mentioned, there are many ammonids, belemnids, sepias, fishes (selachians, many ganoids, teleosts), ichthyosaurs, plesiosaurs, and crocodiles. With the marine forms are associated drifted land plants (cycads, and often a great abundance of conifer logs, now carbonized), beetles, and dragons of the air (pterosaurs).

[5] "Die Jura-Ablagerungen zwischen Regensburg u. Regenstauf," Geognos. Jahresheften 1901, XIV. Jahrg., pp. 178–186.

It is apparent from the above that the common fossils are here again those of the nekton (saurians, fishes with most of the ganoids probably of freshwater habitat, belemnids, sepias) and drifted land plants. Of the benthos, only a few species of bivalves are common, and, while the ammonids are also bottom-dwellers and occur commonly as fossils, their empty shells were probably drifted into this black sea. The crinids were also drifted in, for the only specimens found attached are on conifer wood, hanging head downward; otherwise roots of these pentacrinids do not occur.

In general it may be said that the Liassic deposits and the habitat of the fossils of the time of *Posidonomya bronni* agree best with those of the present Black Sea. Since this is true, it follows that the physical conditions of the *bronni* sea must have been very much like those of the Black Sea, *i. e.*, it was a Liassic Black Sea into which drained rivers, causing the surface waters to be more or less freshened, and bringing land plants, logs, and ganoid fishes. However, there are also marked differences, chief among which is the far less amount of decomposition of the soft parts of ichthyosaurians and sepias, of which fleshy parts are often preserved, a condition that never occurs in the Kupferschiefer. Finally, the abundance of the Liassic bivalves points to the shallow waters of the Modiola ooze of the Black Sea, and therefore to depths of less than 600 feet.

It seems to the reviewer that the present Black Sea, with its great depth and widespread foul conditions, is an exceptional example, and that in all of its features it may have no fossil analogue. The Kupferschiefer and *P. bronni* seas along with the American Ohio sea of Upper Devonian time and the Chattanooga sea of the Mississippian period appear to agree with the essential conditions of the Black Sea, except as to depth. All of the fossil Black Seas appear not to have been deeper than 600 feet.

Foul bottoms are clearly due to a lack of water circulation, either because there is no wide connection with the oceanic areas or because there are inadequate vertical or convection currents. The latter conditions may have been more abundantly attained in warm climates than in cool ones, due to the fact that the heavier colder waters sink to the bottoms and so oxygenate them. In this the present is the exceptional condition when compared with most of

geologic time. In such stagnant areas, be they small or large in area, or shallow or deep, the oxygen is soon consumed by the organisms of the benthos and the depths become stale and lifeless. As the sulphur bacteria are ever present, but thrive best in the stale bottoms, they soon take the ascendancy there and fill the waters with an ever greater quantity of sulphuretted hydrogen, provided they are furnished with the dead organisms on which to feed and thus to increase in number. On the other hand, the sun-lit, aërated surface waters are the realm of the green and assimilating micro-plants, the free algæ, which convert the inorganic carbon dioxide into their organic bodies, and these upon their death rain into the deeps to form the essential food of the bacteria of the foul bottoms.

That depth of water is not the first essential for the production of foul bottoms has been shown by the examples cited (almost from the surface down), but it does seem that large areas must have depths greater than 300 feet, for otherwise the high waves generated by the storms would set up a vertical circulation and so at least periodically replenish the oxygen and take away the foul gases of these depths. Therefore it would seem that Black Seas of large size should be deep (300 feet or more) and land-locked basins whose oceanic connections are more or less cut off by submerged barriers. Smaller areas are the elongated troughs and rounded holes below the general level of the sea floors, while the smallest and shallowest areas are the bays that are more or less separated from the seas by closely approaching headlands, banks, and bars, or the marine swamps that are filled with eel-grass, mangroves, and other modified land plants.

ON THE RATE OF EVAPORATION OF ETHER FROM OILS AND ITS APPLICATION IN OIL-ETHER COLONIC ANESTHESIA.

By CHAS. BASKERVILLE, Ph.D., F.C.S.

(*Read April 23, 1915.*)

It is conceded that the anesthetic agent must get into the blood for distribution and for eventual elimination, whatever theory of general or central anesthesia one may support. The anesthetic agent has normally been introduced into the blood by inhalation or intravenously. It is normally eliminated mainly via the lungs.

The intestinal mucous membrane of vertebrates is well known as an efficient transmitter of gases to and from the blood. Pirogoff[1] appears to have been the first to mention the administration of ether by this route. Liquid ether was used until Magendie gave warning as to the danger of its use and ether vapor was substituted. During the same year Roux,[2] y'Yhedo[3] and Duprey[4] employed liquid ether or aqueous mixtures to induce complete anesthesia. Although Pirogoff's enthusiasm prompted him to predict the supplanting of the inhalation procedure by the rectal method, references to it disappeared from the literature until 1884. Then Mollière[5] revived interest in the method by using a hand bellows for forcing the ether vapor into the intestine. Variations in the technique were introduced during the same year, but the experiences of Yversen, Harter, Bull,[6] Weir,[7] Wancher[8] and Post[9] showed more or less diarrhœa

[1] "Recherches pratique et physiologiques sur l'etherization," St. Petersburg, 1847.

[2] *J. d. l'academie d. Sciences*, 1847, 18.

[3] *Gazette med. d. Paris*, 1847.

[4] *Academie royale de medicine*, March 16, 1847.

[5] *Lyon Medical*, 45, 1884.

[6] *N. Y. Med. J.*, March 3, 1884.

[7] *Med. Rec.*, 1884.

[8] Cong. internat. d. Sciences med., 1884.

[9] *Boston Med. and Surg. J.*, 1884.

and melena as after-effects. These after-effects, which one case of death directly attributable to the procedure, caused the method to again fail in securing serious recognition until 1903 when Cunningham[10] employed air as a vehicle for sweeping the ether vapor into the colon. In 1909 Leuguen, Money and Verliac[11] used oxygen as the vehicle for the ether vapor. Buxton[12] in his splendid book on "Anesthesia" says that he found the procedure most satisfactory for certain operations, for example, those having to do with the mouth, nose, etc., but he remarks "Deaths have occurred." Sutton's[13] introduction of a return flow tube for these gases introduced and unabsorbed constituted a distinct advance in anesthesia by colonic absorption.

In an effort to avoid certain well-known difficulties in intravenous anesthesia, Gwathmey experimented with mixtures of normal saline solution and ether per rectum. The concentration of ether in the aqueous solution was so small that excessive volumes of liquid were needed, and furthermore the ether parted from the solution so very rapidly that experimentation along those lines was abandoned. Gwathmey then applied a solution of ether in olive oil. As oil and ether make perfect solutions in all mixtures, it was his hope to reduce the total bulk of the fluid introduced into the colon by using a stronger solution of ether in oil than is possible with any known aqueous mixture. As oils are lubricants, it was also hoped to avoid the irritation of the mucous membrane previously noted. The ether may always be separated from the oil by warming, but unless the temperature of the mixture is suddenly raised to an excessively high point, the ether passes off deliberately. It was thought that the evaporation of the ether would induce some cooling of the mixture with a consequent checking of the evaporation and its absorption. These premises coupled with slow absorption by the colon in comparison with the rapid elimination by the lungs would auto-

[10] Cunningham and Leahy, *Boston Med. and Surg. J.*, April 30, 1905; *Vide* also Dumont, *Correspond. Bl. f. Schweitzer Aerzte*, 1903; 1904; 1908; Krugeline, *Wiener klin. Woch.*, Dec., 1904.

[11] *Compt. rend. Soc. Biol.*, June, 1909.

[12] "Anesthesia," London, 1907.

[13] For full account of technique and literature, see "Anesthesia," by Gwathmey and Baskerville, Appleton, New York, pp. 431–457, 1914.

matically regulate any anesthesia that might be induced in this manner. As a result, Gwathmey presented a paper before the seventeenth International Medical Congress in London in 1913 on the work with animals done by himself and Wallace.

At the request of my co-laborer, Gwathmey, I undertook an investigation on the rate of evaporation of ether from oils to secure the following information that might be of service to him in his further application of his ideas with human subjects:

1. A comparison of the rate of evaporation of ether from different mixtures of ether and the same oil.

2. A comparison of the rate of evaporation of ether from the same per cent. mixtures of different oils and ether.

3. The influence of surface on the rate of evaporation was determined.

As the result of much preliminary experimentation, the following mode of procedure was settled upon. Large glass tubes were calibrated to 1 c.c. from 20 c.c. to 105 c.c. The mixtures of 25, 50 and 75 per cent. of oil and ether were carefully placed in the tubes. The tubes were weighted with lead and placed in a thermostat, whose temperature was so regulated as not to vary more than $\pm 0.03°$ C. from 37° C., the same being controlled by a toluene + mercury temperature regulator. All connections (gas, water, etc.) were made with lead pipe for safe use over night, as occasion arose. The water in the bath was stirred by a system of paddles and shaft operated through belt and pulleys by a small hot air engine. The tubes were immersed in the bath to within 2 cm. of the tops. During the first five minutes two readings were made in each case to get the highest point to which the volumes expanded upon heating up to 37° C. After that readings were made every five minutes for two or three hours.

Since the evaporation of any liquid depends upon the partial pressure of that liquid at its surface, the higher the glass wall above the surface of the oil-ether mixture, the heavier the column of ether vapor resting on the surface of the mixture, the slower will be the evaporation, consequently the different oil mixtures with the different percentages of ether were experimented with in the same tube filled to the same height in each experiment.

In the experiments to determine the influence extent of surface played upon the rate of evaporation, the same precautions were taken as to height of walls of the containing vessels. In the largest areas worked with, this involved using as much as 600 c.c. of the mixture. As the 75 per cent. mixture had been found most satisfactory clinically, this was determined with that mixture only.

The ether used was that prepared under my supervision and was 97 per cent. absolute with 3 per cent. absolute alcohol, being free from acids, aldehydes, and water.

The oils used were of three types, vegetable, animal and mineral, being respectively, olive, cotton seed, corn, peanut and soya-bean; cod-liver and lanolin (anhydrous); and Russian mineral oil. All the vegetable oils, except olive, were refined by a process devised by

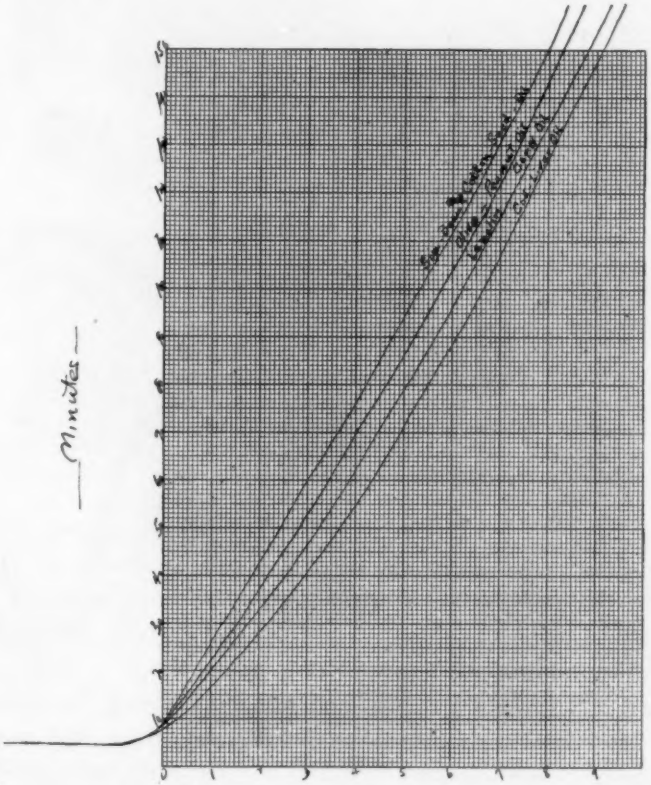

CHART I.

the author[14] and were neutral. The other oils were purchased in the open market.

The experimental work was carried out by Mr. Hyman Storch, under my direction.

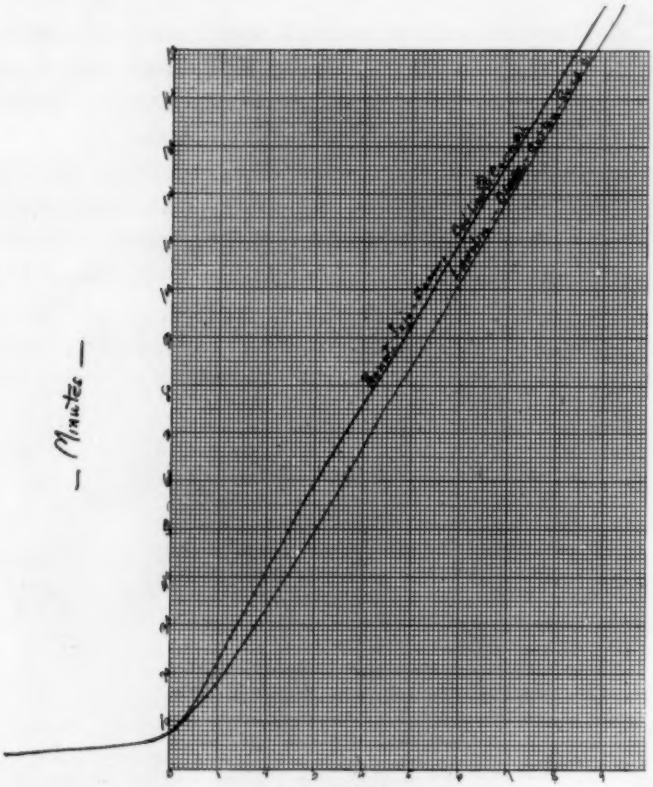

CHART II.

The data obtained for the 25, 50 and 75 per cent. mixtures vegetable and animal oils are shown graphically in Charts I., II. and III. In the curves the abscissæ show the percentage of ether evaporated (based on volume measurements) and the ordinates time of the evaporation.

Chart IV. (selected at random from charts made for each oil) shows the difference in rate of evaporation 25, 50 and 75 per cent. mixtures with one oil.

[14] "Refining Oils," *Oil, Paint and Drug Reporter*, May, 1915.

Chart V. shows the effect of increased surface on the rate of evaporation. One oil only was selected to show the principle, which is: the rate of evaporation bears a direct ratio to the surface exposed.

These experiments were made in glass, hence they do not disclose all the factors in the conduct of such mixtures in contact with the walls of the colon, for there the principles of osmosis and diffusion are involved. But these observations demonstrated several striking facts:

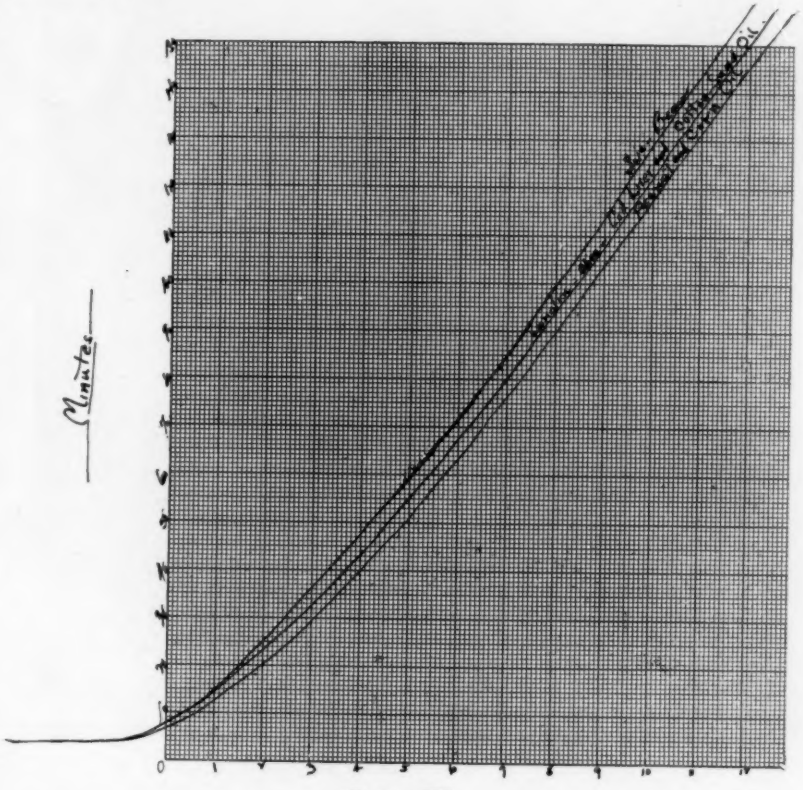

CHART III.

1. While ether boils at 34.6° C., it does not escape violently from an oil-ether mixture, as from an aqueous mixture when the mixture is heated higher, namely, to the body temperature of 37° C.

2. The *rate* of separation of ether from the oil quickly acquires a definite and fairly fixed speed.

The significance of this conduct cannot fail to be of great importance, for by this means the proper content of ether may be main-

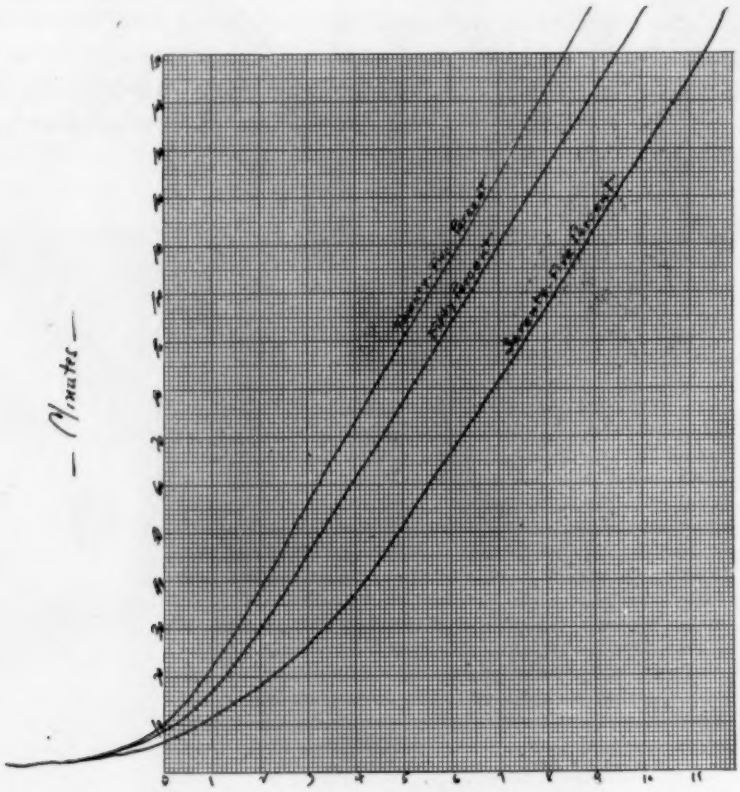

CHART IV.

tained in the blood to produce any desired physiological effect that has a quantitative relation thereto, for example, the third or surgical stage of anesthesia.[15]

The last mentioned has been demonstrated clinically by Wallace, who found respiration and blood pressure fully maintained, and Gwathmey and others with records to date of about 1,000 human cases. So far, not a case of post-ether pneumonia has been encoun-

[15] In this connection it may be stated that about 30 mils of a 75 per cent. mixture to 20 lbs. of body weight is administered as an enema.

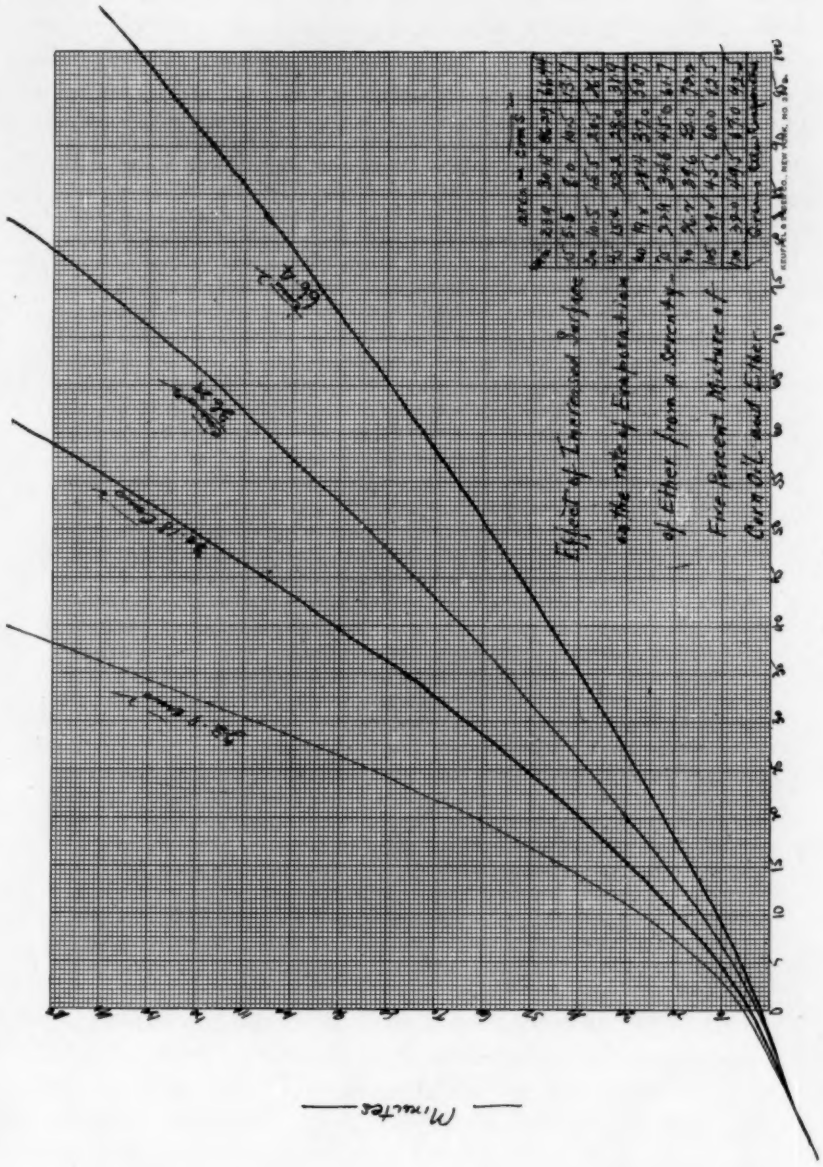
Minutes
Effect of Increased Surface
on the rate of Evaporation
of Ether from a Security
Five Percent Mixture of
Cod Oil and Ether.

CHART V.

tered. The after-effects usually associated with inhalation anesthesia, unless induced by the most improved modern technique, are virtually absent, including post-anesthetic nausea. Its use for special cases involving the head, breathing passages, etc., is superior. Although having had the privilege of attending clinics, I am not qualified to pass judgment upon its value, but from what I have learned, if necessary, "Give it to me that way."

COLLEGE OF THE CITY OF NEW YORK.